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Final Report

SEMI-AUTOMATIC TARGET RECOGNITION DEVICE

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LITTON SYSTEMS, INC.

Data Systems Division

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221 Crescent Street

Waltham 54, Massachusetts

Contract AF30(602)-2494

Prepared for

Rome Air Development Center

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Prepared by

G. Sebestyen
A. Manevitz

Approved by

George Sebestyen
Technical Director

John W. Gerdes
Assistant Manager

LITTON SYSTEMS, INC.
Data Systems Division
Communication Sciences Laboratory

AIR FORCE FORWARD

This study was initiated by the Reconnaissance and Targeting Branch of the Information Processing Laboratory as a part of the Air Force program to develop an interpretation capability compatible with present and future reconnaissance systems. Specifically, the purpose of this study was to design, construct, and test a Semi-Automatic Target Recognition Device that would detect targets on aerial reconnaissance photographs.

Most designers of recognition schemes try to solve the complex problem of gray scale target recognition by simply selecting an easily measured characteristic such as the shape, the cross-correlation function of it with a selected aperature, the power spectrum, etc., and then try to divide the patterns into two or, at best, a few classes. However, all selections are based on the measurement of a single characteristic that is either invariant or predictable for a class. Unfortunately, the patterns as they appear on gray scale aerial photographs cannot be analyzed as if they were simple black and white characters of solid geometric shapes and so they do not lend themselves to such a simple analysis. Therefore, several characteristics are measured and as more are measured, the better the chance is of identifying the target. The measurement of several different and independent characteristics requires a more complex method of making a decision than a simple dichotomy. The techniques for the more complex decision making process have been under development from the introduction of a generalized distance function in 1936 by Mahalanobis to the very recent research of Sebestyen. It is possible to recognize targets by measuring a number of characteristics of the photograph by combining these measurements into parameters, and then by comparing the parameters with stored reference data. This technique has been fully illustrated in this document.

The parameters selected by Litton have been successful for the limited goals of the work reported on in this document. There are still many parameters that could be developed. It is possible to vary the input parameters and use the approach of the Semi-Automatic Target Recognition Device for anything from cloud detection to multiple intelligence correlation. It is hoped that this report will stimulate research along many lines.

FOREWORD (Cont.)

This document presents the results of a scientific investigation. It is hoped that it will stimulate interest in the problem and will serve as an indication of our interests. Comments on this work, scientific or philosophical, are invited and should be addressed to the contract scientist.

LYNWOOD D. SINNAMON, Jr.
CONTRACT SCIENTIST
ATTN: RAWICC
Rome Air Development Center
Griffiss Air Force Base, New York
April 1963

ABSTRACT

~~This report presents~~ a summary of the work ~~performed by the Communication Sciences Laboratory of Litton Systems, Inc., under Contract~~ No. ~~AF30(602)-2494,~~ to develop techniques for machine recognition of targets on aerial reconnaissance photographs and to construct a device which demonstrates the feasibility of these techniques.

The results of the study phase of this procurement led to the choice of a parametric approach to target recognition and the decision to employ both electronic and electro-optical means to extract the necessary parameters. The Semi-Automatic Target Recognition Device (SATRD) developed on this contract utilizes a flying spot scanner with a rotating raster to extract parameters related to target texture and a two-channel area-matching optical system to detect specific shapes. An automatic learning and recognition computer program was utilized to evaluate the electronic parameter data extracted from a set of 150 aerial photographs, consisting of 15 samples of each of 10 strategic target classes. Due to a lack of sufficient light output from the scanner, optical parameters were not extracted from the set of aerial photographs. However, results are reported on a series of experiments that indicate the feasibility of area matching for the detection of specific shapes--with special applicability to the recognition of tactical targets.

In keeping with the original aims of this contract, recommendations are made to utilize the SATRD for the evaluation of additional parameters and for the extraction of data from a much larger set of reconnaissance photography, followed by computer evaluation of classification results and the elimination of those parameters displaying excessive redundancy.

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I. INTRODUCTION

The large number of photographs that result from aerial reconnaissance missions make the task of the photo-interpreter a laborious one. It is therefore imperative that work progress on the development of automatic or semiautomatic devices which augment the human photo-interpreter by performing some of the initial sorting and cataloging functions preparatory to the main task of extracting military intelligence from an analysis of aerial photographic reconnaissance.

An important step on the road toward automatizing initial sorting and cataloging functions is the construction of a device that can recognize, from photographs, selected target types of military interest, regardless of the orientation, location, and size of the target on the photograph, and regardless of the fact that different targets of the same type have, in general, quite different physical appearances.

One of the important problems of aerial target recognition is that of isolating a region on the photograph which contains only a single target: another concerns the problem of recognizing this isolated target as a member of one of several target types of interest. The first of these, although a challenging problem which has by no means been solved satisfactorily in an economical fashion, has received considerable attention in the past with the result that several solutions are feasible. The solution of the second problem, that of recognizing a single target as a member of one of several target types, is pivotal to the success of this program. This problem involves the development of working definitions of target classes such as airfields, bridges, industrial complexes, urban areas, etc. The definitions must be expressible in terms of physically measurable parameters which express the invariant properties of the target classes, i.e., those properties which targets of the same type have in common.

Objectives of this program are to develop techniques for machine recognition of aerial photographs and to construct a device which demonstrates the feasibility of implementing these techniques. The results of the study phase of the program, in addition to providing a survey of applicable recognition techniques, led to the choice of a parametric approach to target recognition.

In this approach a target is represented by a set of measurements, each representing a different attribute of the target under surveillance. A target class is then defined as a given set of permissible combinations of these attributes. The study effort reported in this document consisted of an investigation of the type of attributes or properties that are useful for target recognition purposes and can be extracted from the aerial photography in "real time". The method of processing the extracted parameter values to effect target recognition has also been studied. The feasibility of extracting the chosen parameters by electronic and electro-optical means has been demonstrated. The limitations of these parameters and suggestions for further improvements are made.

The general techniques of target recognition are discussed in Chapter II indicating the manner in which target attributes may be extracted from the photographs. Chapter III contains a discussion of the methods of data processing that must follow the extraction of parameters from the aerial photographs. The consideration of the choice of parameters and their instrumentations are discussed in Chapter IV. A brief description of the experimental hardware is given in Chapter V, and more fully discussed in Appendix I. Test photographs, conclusions and recommendations are presented in Chapters VI and VII, respectively.

II. TARGET RECOGNITION TECHNIQUES

Within the past several years, a number of approaches have been followed in attempting to develop an automatic or machine-aided photo-interpretation capability. Most of these were examined during the initial phases of this program to determine which of the more promising techniques should be considered for incorporation in the semi-automatic recognition equipment. As a result of this initial survey, the parametric approach to target recognition appeared to offer the best solution to the problem, and therefore was selected as the technique to be developed, refined, and implemented in the recognition equipment. In order to appreciate the selection of the parametric approach, it will be useful to review briefly some of the limitations inherent in the alternate techniques.

Traditionally, optical matching of target shape with stored reference shapes has been extensively investigated for many recognition applications, including the use of optical correlation techniques as a method of photographic target recognition. The obvious shortcomings of this technique are that it is translation, magnification, and orientation sensitive, even if the shape of the actual target matches exactly the shape in storage. A number of methods are available for eliminating the translation sensitivity and for reducing the orientation sensitivity of shape correlation techniques. Sensitivity to magnification, however, is a problem that still has not been solved. The complexities of such "pre-normalization" of the image <u>before</u> it can be matched to the shapes in storage are considerable and are probably the major shortcomings of shape correlation techniques. Optical correlator outputs are also dependent on the contrast of the input image although this dependence is usually eliminated in a comparative evaluation of the input image with each of a number of stored reference shapes. The major problem, however, is that different examples of an input image of the same type (different examples of airports) are not alike in shape; that is they do not exhibit a template-like matching similarity. In a function space in which one might consider the figure to be represented, this means that member functions of the class of functions representing a target type are not well correlated. That is they do not lie near each other in a mean square sense. Many different investigations were carried out to overcome this limitation by considering various permissible distortions of the figure before requiring that a template-like match between the distorted image and the reference shape in storage should match. Invariance after affine transformations, membership of the shapes in the same topological groups, are examples of investigations along these lines. Although of some academic interest, these techniques are far removed from implementation in the form of a machine operating in real-time.

Spatial filtering as a means of extracting the useful information from the redundant image (redundant from the point of view of recognizing the target type) has also been investigated. As a means of enhancing certain characteristics of the imagery and detecting the presence of certain characteristics, this technique is very useful. The basic limitation of the technique is that it is not suitable for recognizing the many different manifestations of targets of the same type. It suffers in many respects from the same shortcomings as shape detection by the method of looking for a match between the input image and the set of stored reference shapes. As a method of measuring certain attributes of the photograph, the technique is useful but difficult to implement.

Another means for detecting shapes is by the employment of techniques using a programmed search or curve following. This technique scans the picture by following lines or directions of significant information. One might look, for instance, for a boundary exceeding a given threshold magnitude, stop the systematic search and initiate a line or contour-following search, e.g., to follow banks of rivers in order to locate bridges. Essentially no work along these lines has been done to date because the implied complexity of the hardware exceeded the scope of most investigations. Scanning systems under computer control have been constructed, however their use is limited to the performance of rather elementary operations which can just as well be performed by other means. It is noteworthy to mention that systems of this type, in which the scanning and computational procedure is dependent on features of the photograph as they are encountered, are basically similar to adaptive control systems.

In the parametric approach followed in this program, the input photography is scanned, frame by frame, in a systematic manner to cover each and every cell so that it may be examined for target content. The content of the cell is then characterized by a parametric description in which each parameter is a measure of an attribute, and the set of attributes (their quantitative values) are used to describe the contents of the cell. Thus, we may obtain a description of a specific cell as one which exhibits a large dynamic range of contrast, a large number of elementary details of circular shape, a dominance of few colors, a uniform spacing between detail elements, etc. If the descriptors are well chosen, this would sufficiently well describe a tank farm and would permit its discrimination from other target types. A target type is characterized by the permissible combination of parameter values that arise from the observation of many different targets of the same type. In mathematical terms the joint probability density of the numerical values of the different attributes serve to characterize the target classes. This method of representation and this method of rendering classificatory decisions is within the framework of statistical decision theory, a mathematical discipline concerned with decision making based on multi-parameter data and satisfying certain conditions of optimizing the decision making process.

The parametric recognition technique, therefore, is one which allows the systematic scanning of the entire photograph, the measurement of a set of defined parameters, and the method of representation of the photograph in terms closest to that of a human narrative description. It further permits the application of already well tried and optimal data processing techniques for decision making. The question then remains how one should obtain the parameters, what techniques are instrumentable, and how one can define useful descriptors of the imagery in instrumentable form. Other sections of this report will provide answers to these questions.

In conjunction with the theoretical development of the parameter recognition procedure an experimental recognition device was constructed to verify the feasibility of the technique, and to aid in the selection and evaluation of characteristic target area descriptors. The basic target recognition system consists of the physical hardware necessary to position a frame in the viewing aperture by mounting a role of film on a transport having 2 degrees of freedom.

The input data format consists of rolls of aerial photographs of 9" x 9" frame size. The photography is vertical and is typical of the aerial reconnaissance photography used by the U. S. Air Force. Scale of photography used in this program is approximately 1:20,000. The aperture is illuminated by a flying spot scanner which can be operated in several different modes depending on the type of parameters with which the content of the viewed aperture is described. A detailed description of the experimental equipment will be given in a later section. The following description is given only to indicate the manner in which target recognition would proceed, using the recognition device.

The basic system allows the placement of a cursor on any selected point of the photographic frame. This serves as an interrogation signal to the automatic target recognition equipment, asking it what type of target is contained in the small neighborhood or cell on which the cursor is centered. The machine responds to this query either with a printout or other output symbol indicating which of the finite set of target types is most likely contained in the cell, or provides a set of numbers (one corresponding to each target type) which indicates the probability with which the cell contains an urban area, a railroad yard, a bridge, etc. If any of the probabilities exceeds some predetermined (operator controlled) threshold value, an alarm may be sounded and the x-y coordinates of the cursor position, at the time the alarm sounds, may be recorded. To speed up the operation of the basic system described above, it is necessary only to replace the human operator control of the cursor with an automatic scanner to systematically scan every cell of the photographic frame. The human operator then is required only to advance the film so that the required frame is in position, whereupon the 2-degree of freedom film transport mechanically scans all cells of the photograph. Each cell, coming under the observation of the flying spot scanner, is then processed electronically to extract the parametric descriptors of the content of the cell. These descriptors are processed to compute the probabilities of membership of the cell contents in each of the target classes. The probabilities are examined to determine whether they exceed the threshold values and to determine which probability is the maximum. An output is then generated by displaying (by use of different symbols) the locations of the most probable target types at each x-y coordinate of the frame. If the probability is too low for all target types, no output display is obtained and the operator advances the film transport to load the next frame into the processor. Of course, it is possible to feed the output information to a small computer to count and tabulate the targets and tag the frame with a verbal description of the target types and locations within the frame.

The method of evaluating the parametric descriptions of the cell contents has been adequately proved on other contracts. In fact, a special purpose computer has been designed to perform the data processing on a single parametric description in 17 1/2 milliseconds. If necessary, further speed up of this operation can be implemented. Typically if there are 100 cells into which the picture is divided, a total processing time of the frame would be approximately 2 seconds. If necessary this processing time (from the point of view of data processing techniques) could easily be reduced by a significant factor. Limitations on the frame processing time, however, are imposed by the parameter extracting circuitry. The parameter extraction techniques investigated in this program are basically comparable with the processing speed requirements of the data processor, although their implementation in the hardware constructed for this program is much slower. To permit economical proof of the feasibility of techniques, parameters are extracted sequentially in the present equipment. Several groups of parameters. however, can be extracted in parallel by a straightforward expansion of the existing device. To limit the scope of the investigation, vertical 9" x 9" aerial photographs with a ground scale of 1:18, 000 to 1:30, 000 were used. From over 2000 frames provided by the agency, approximately 100 were selected as a representative data sample for parameter extraction and testing of recognition methods. A further screening of photographs was performed on the basis of scale. A total of 101 frames with scales in the range of 1:18, 000 to 1:30, 000 were chosen as the final sample on which to perform analysis and test techniques. These photographs, which are described in the table, show target classes of interest and lie within a sufficiently narrow range of scales that early data analysis can be directed to basic techniques rather than details associated with scaling of inputs.

ROLL	Urban Areas		Industrial Areas		Tank Farms		Railroad Yards		Airfields		Bridges		Ports		Ships (in port)		Ships (alone)		Farms		Clouds		Total Selected Frames
	Frames	Objects	Frames	Objects	Frames	Objects	Frames	Objects	Frames	Objects	Frames	Objects	Frames	Objects	Frames	Objects	Frames	Objects	Frames	Objects	Frames	Objects	
1	27	27	20	27	6	14	6	10	1	1	17	83	4	4	3	56			20				28
5	46	48	38	47	10	23	8	12	8	8	10	39	5	5	3	21			27				45
6	8	10	6	6	2	4			2	2	3	14							10				10
10	8	8	5	5	1	2	3	4	10	10	6	17		1	1	2	2	2	1		12		18
TOTAL	89	93	69	85	19	43	17	26	21	21	36	153	10	10	7	79	2	2	58		12		101

Figure 2. 1. Summary of Selected Frames

III. TARGET RECOGNITION BY PATTERN RECOGNITION

The purpose of this section is to describe the method of approach used to achieve target recognition on aerial photographs. It should be noted that the recognition of a target, such as a particular but unspecified urban area, cannot be accomplished by correlation with a stored reference photograph of an urban area (unless, of course, the two are photographs of the same city). Little, if any, congruence between the reference and the new input is expected to exist; yet correlation techniques are essentially measurements of congruency using a mean-square error criterion. The techniques described in the following are far more general but they include correlation as a special case.

All problems of target identification, whether the targets are "industrial complexes", "bridges", or "airfields", are joined by a common bond which permits their solution with a unified approach. Target identification requires the ability to recognize membership in classes, where classes are known only from a set of their examples. Suppose, for instance, that we are given a set of photographs of urban areas, the photographs being taken over several different cities from many different altitudes. The set of photographs thus obtained constitutes the set of samples from which the invariant properties of urban areas must be extracted. Similarly, let us assume that we are given sets of photographs of other target classes, such as industrial complexes, airfields, bridges and the like. We wish to discover from these photographs how to measure membership in the classes "urban areas", "industrial complexes", "airfields", "bridges" and (by identifying photographs or parts of photographs as members of one or another of the classes) how to solve the target identification problem.

Consider all the information potentially pertinent to the recognition of targets from aerial photographs to be represented by a point or vector in an N-dimensional observation space which serves as a model of the physical world. Each dimension expresses a property of the photograph (or a part of the photograph), a type of observation that can be made and measured. These properties, parameters, attributes or just plain measurable quantities form the vocabulary of descriptors with which any target is described. The total set of descriptors and the entire information we choose to use from the photograph is represented by a vector $v = (v_1, v_2, \ldots, v_N)$, the coordinates of which are the results of N quantitative tests made on the photograph. Generally, useful measurable quantities probably pertinent to the recognition of target classes of interest may be considered to form a vector space. A study of the method of selection of parameters and the results obtained with them is presented in the next chapter.

In accordance with the method of representing pictorial data discussed above, an ensemble of photographs which is known to contain airfields may be represented by an ensemble of points scattered within some region of the N-dimensional space. One might also expect the distances between points that represent photographs from another class of targets (such as urban areas) to be small, on the average; but the distances between different sets of points, one representing airfields and the other representing urban areas, are expected to be large. Unfortunately, this state of affairs cannot in general be expected to exist. If it did, simple correlation techniques such as those instrumented by the Perceptron and other similar devices could successfully separate the targets of different classes from one another. In many practical problems, such as aerial target recognition, the classes are not linearly separable (not separable by hyperplanes in the N-dimensional vector space) and their members are not contained in disjointed simply connected regions of the space of observable parameters. In these cases the methods of statistical decision theory can be invoked to aid in target recognition. From the point of view of maximizing the probability of correct decision, the a posteriori probability of each of the target classes must be evaluated and the boundaries of the decision regions must be determined on the basis of a comparison of these probabilities. Without loss of generality this is stated by equation (1) for the case where we wish to decide whether or not the observed vector (example of a target) $v = (v_1, v_2, \ldots, v_N)$ is more likely a member of target class A than of B.

$$\text{Decide } v = v_1, \ldots, v_N \in A, \text{ if } \frac{P(A/v_1, \ldots v_N)}{P(B/v_1, \ldots, v_N)} > 1 \qquad (1)$$

This decision rule can also be expressed in terms of conditional joint probability densities and a priori probabilities of the two target classes. Unfortunately, the probability densities are usually unknown and the target classes are known to the decision maker only through a finite number of their samples. From knowledge of the correct decision at only a finite number of points (knowledge of the correct classification of a set of samples) machine learning in pattern recognition attempts to define a decision for each point of the vector space and thus provides a decision maker with the ability to classify any new target according to its target class. The computational procedures for developing a generalized non-linear discriminant function that minimizes the expected error while it defines a decision at each point of the space from knowledge of a finite number of samples has been reported on in the literature.[1,2] Further simplification of the computational techniques in an effort to make both learning and recognition a "real-time" realizable operation is discussed in detail in the literature.[3]

The method of data processing (the method of processing parametrically represented targets) is not discussed in detail in this report in view of the extensive reporting of these techniques in the literature. These methods construct approximations to the joint probability densities of each of the target classes from a finite number of samples. These probability densities are employed in a method of "likelihood ratio" computations, a method which is optimum in a decision theoretic sense.

The case for the employment of decision theoretic techniques that minimize the probability of making incorrect decisions can be made readily. It has been made eloquently in many places in the literature. The practical difficulty in the employment of decision theory on multiple variable inputs is the difficulty with which the required probability densities can be obtained. Probability densities are either, 1) derived from physical considerations of the target types between which separability is to be achieved or 2) constructed experimentally from the collection of a large number of sample targets. The basic game played by decision theoretical approaches is the following.

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[1] Sebestyen, G.S., "Classification Decisions in Pattern Recognition", Technical Report 381, MIT, April 25, 1960.

[2] ______________ "Decision Making Processes in Pattern Recognition", The Macmillan Company, 1962.

[3] ______________ "Pattern Recognition by an Adaptive Process of Sample Set Construction", IRE Trans. on Info. Theory, Vol. IT-8, No. 5, September, 1962.

Assume that someone gives us two or more very large bags full of sample vectors. We are told that bag No. 1 contains an infinitely large number of vectors where each describes the numerical values of certain preselected physical properties of a specific target of Type 1. The second bag similarly contains an infinitely large number of vectors representing the different combinations of property values encountered when viewing targets of Type 2. We (or the machine) are supposed to examine the two bags of infinite collections of targets and are expected to develop a decision procedure, without the actual storage of the samples examined, through which successful target classifications can be accomplished. After randomly drawing a sample vector out of one of the two or more bags of samples, target classification consists of the decision maker deciding, with a minimum probability of error, which bag the sample was drawn from thus classifying the target type. The multivariate analysis technique employed in this program constructs automatically the decision rule which makes such a decision.

In practice, of course, an infinite number of samples of target classes is not available. Instead we have a finite and usually small number of samples. At best we can assume that the samples are representative of the target classes in question and have probability densities quite similar to those we would obtain by examining a much larger sample size. If this requirement is satisfied (by applying good engineering judgment in the selection of samples), the decision theoretical methods that decide membership on the basis of the ratio of conditional probability densities of the samples, result in a minimum number of misclassifications.

IV. PARAMETER SELECTION

Before the mathematical techniques described in the previous section can be applied to the classification and recognition of targets from aerial photographs, it is first necessary to select a suitable vector representation of the target areas. The purpose of this chapter is to discuss the types of measurable quantities which may be used as the dimensions of the vector space, discuss the sources of parameters, the advantages and disadvantages of the various techniques and discuss the nature of the equipment with which such measurable quantities can be extracted.

The objectives of this program are to develop and prove the feasibility of extracting those parameters which will serve as descriptors of a target area contained on the photograph under observation. With the parameters one would like to describe the type of "texture" and "distinctive features" of the small areas. Examples of textural descriptors are "striped", "regular", "irregular", "containing rectangular objects", "uniform object size", "variability of object density", "predominance of the area's content of a given shape", and the like. For instance an urban area has a texture that gives a generally cross-hatched appearance with object sizes varying between fairly well established limits and object reflectance yielding a large contrast range. The individual component objects making up the urban area are generally rectangular in shape, with a fairly uniform spacing between significant line boundaries encountered on the image. Line intersections occur predominantly at 90 degree angles. Such a description of an urban area certainly differs from that of a tank farm which contains generally uniform spacing of circular shaped objects of the same color in a field generally devoid of photographic detail. The circular tanks have only a few discrete sizes and their colors are usually the same.

The objective of the parametric representation of target images is to re-state the verbal description in terms of a set of predetermined measurements made on the photograph. A brief list of typical measurements, properties and attributes is given below.

a) Content of photographic detail

b) Content of circular objects

c) Parallel line content

d) Content of right angle intersections

e) Average size of object detail

f) Uniformity of the spacing between object detail

g) Uniformity of density of object detail

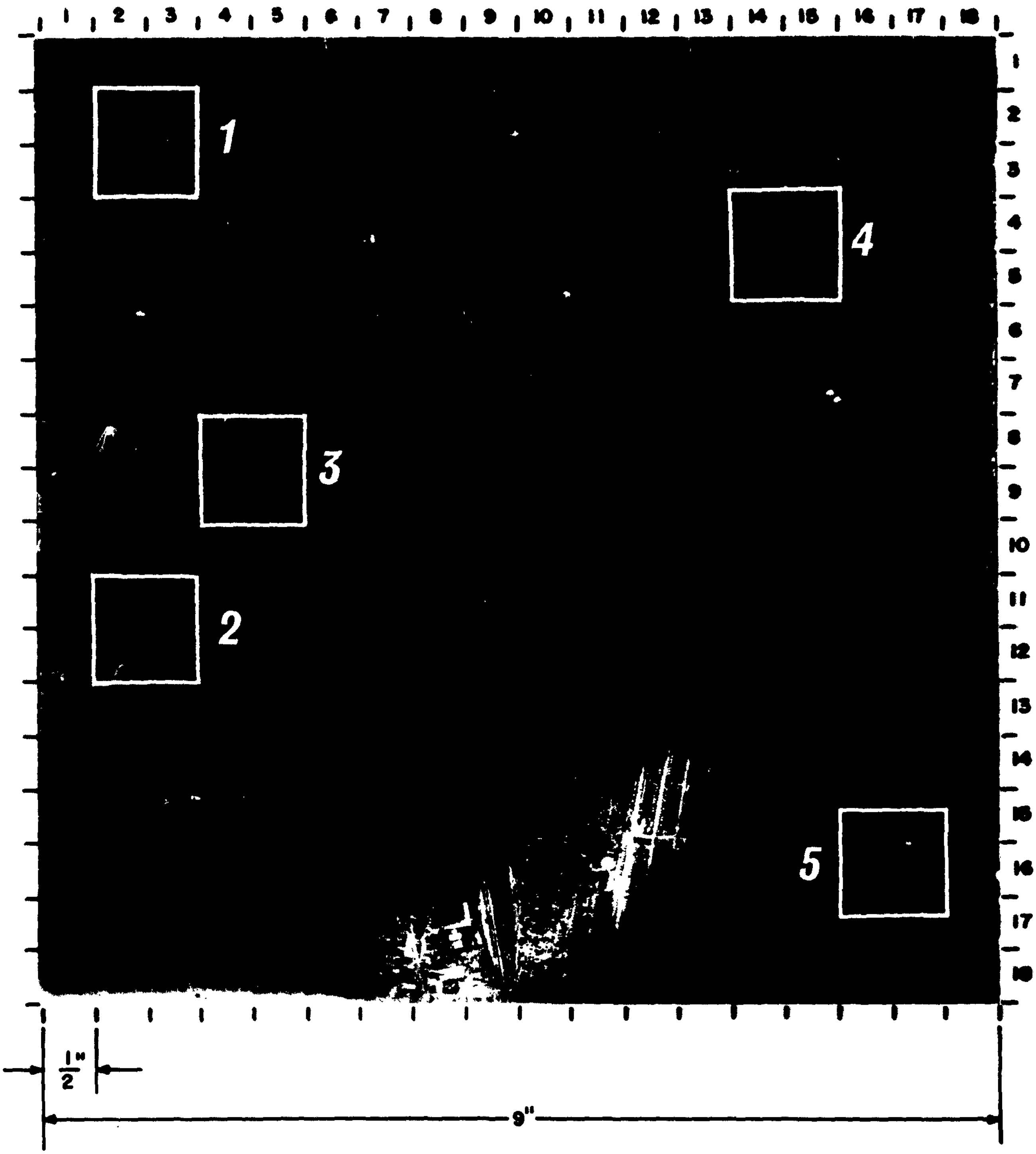
h) Length to width ratio of object detail

The above listing of parameters describes the texture of the area under investigation. Illustrative examples of targets recognizable from their texture alone are urban areas, certain types of industrial complexes, tank farms, and railroad yards. Some of these are shown in Figure 4. 1.

Not all targets, however, can be recognized from their texture alone; a bridge, a harbor, an airport, and missile launching site are examples of targets which must be described in other terms. A bridge, for instance, may be defined as two parallel lines which bound a strip whose density differs from the density of the area on either side of the strip. The area surrounding the strip (except at the ends of the strip) is generally devoid of photographic detail and has a constant density level throughout. Further characteristics are the length and width of the bridge, which will normally fall within known limits. The intersection of the bridge with the shoreline will, in most cases, form an angle of approximately 90°. The area surrounding the ends of the bridge often exhibits a different gray level than the bridge itself, and in addition, contains significantly more detail than the bridge or the area abutting the sides of the bridge.

A description of the above type clearly depends on the detection of certain distinguishable features not determinable from the target texture alone. In fact, the establishment of a given geometric relationship between different distinguishable features or events is critical in the recognition of targets of this type.

Texture dependent quantities of parameters may be extracted by operations on the photographs which are suggestive of "filtering" in electronic signal processing. The difficulty encountered with "filtering" operations is that they can only filter and detect specific textures well defined in terms of size. Orientation and spacing of its structural elements, e.g., the detection of parallel lines by filtering type operations, can be implemented



SCALE : 1" = 1670 feet

(ROLL 5, FRAME 47, ALTITUDE: 10,000 ft.)

Target No.	Class
1	Ocean
2	Industrial Are
3	Railroad Yard
4	Urban Area
5	Tank Farm

Figure 4.1 Texturally Described Target Areas

generally only when the orientation of the lines and the spacing between them is known. Alternatively, a large bank of spatial filters is required to adequately process aerial photography. A bank of electronic filters may be constructed in a compact and economical fashion; however, a bank of spatial filters is not as readily implementable. The difficulty of implementing a system operating in real-time, employing spatial filtering as a means for extracting parameters, seems prohibitive particularly in view of the feasibility of extracting parameters of generally the same type by electronic means to be discussed later.

Electronic processing of the video output resulting from the judiciously chosen scanning of the aerial photographs can extract most of the parameters describing the texture of the area under observation. These techniques, however, are much less applicable to the detection of specific structural shapes. Content of photographic detail, spacing between elements of the detail structure, scale and rotational sensitivity of the texture, variability of gray levels, uniformity of spacing between picture elements, measurements of angles between principal axes of orientation are among the types of measurements that can be performed electronically.

The identification of specific structural features by detection and recognition of geometrical shapes is better accomplished by techniques that "match" the detected shapes against a stored library of shapes in the machine's memory. The obvious sensitivity of these techniques to orientation, translation, scale, and contrast must be minimized before this match technique can be fully utilized. It is important to point out that for strategic targets it is generally not necessary that the target shape itself be matched against one or more shapes in storage. Rather, elementary building blocks of which the picture is composed should be matched against shapes stored in the machine's memory to determine their presence or absence. An electro-optical correlation technique, "area matching" developed on an earlier contract for RADC* can be employed to detect the presence of such distinctive features. Area matching, as a basic technique, is implementable in real-time as evidenced by character readers employing this principle. Modifications on the basic technique developed during the present contract reduce the scale, orientation, translation, and contrast sensitivity of the area matching technique. The basic output of these electro-optical parameters is expressible by correlation coefficients computed between the input image (in a specific orientation, position, and scale) and one or more images in storage. As such, the correlation coefficient is a measure of the "template-like similarity" between the shape in storage and the portion of the image under observation, as well as a measure of the average contrast of the input image. The dependence upon contrast is

*"Aerial Reconnaissance Electronic Reader", Contract AF30(602)-2002

undesirable since it seems only to modify the measured correlation in an unpredictable way even for an exact pattern match. Our own work using these techniques proved that considerable sophistication in the use and control of automatic gain adjusting devices must be made to reduce the dependence of area matching systems on the uncertain dynamic contrast of the input imagery, that is, the variation in contrast in going from one small neighborhood to another. Switching from orthogonal Polaroid mask techniques to a two color optical system, rapid rotation and translation of the stored shapes, and integration over the variable parameters makes the output of such modifiedarea matching techniques capable of indicating the degree of content of given structural shapes independent of the uncertain translational, rotational, and contrast parameters of the input imagery.

Unfortunately there are basic limitations on the speed of electro-optical parameter extraction, limitations which exist to a much lesser extent in the completely electronic implementation of textural properties mentioned above.

A third, very important type of parameter not yet discussed measures the geometric relationship between different textural or other features and between areas containing these features. A harbor, for instance, in many respects is merely an industrial complex located near a large body of water. Thus the distance between areas having certain features (those characterizing an industrial complex) and another area containing different features (those characterizing a body of water) is an important attribute to note. The extraction of such parameters would generally imply a "result-dependent" programmed search. That is to say, if we encounter an area exhibiting properties of an industrial complex, then we should search, in perhaps ever expanding circles, for an area exhibiting a property of a body of water. If we can find such an area within some predetermined distance, and if several other conditions are also true, then we can announce that the area under investigation is a harbor. The complexity of operations of this type involve the excessive use of storage facilities and of search operations that are under the control of a program. In other words, we may be talking about a complex, computer-controlled device. Alternatively, it is possible to relegate the establishment of such geometrical relationships to specially chosen not "result-dependent" electronic parameters. An illustrative example of such a parameter is one which measures the distance between the area under surveillance and the nearest area of large photographic detail. This distance is an attribute that can be added to the list of attributes already extracted to augment the description of the area under observation. The extraction of such an attribute can be performed in a manner not requiring a programmed search.

The following sections of this report describe the specific electronic and electro-optical parameters that were investigated on this program. Electronic parameters, for the purpose of this report, are those which are obtained by analog or digital processing of the video output of a scanned photograph where both the method of scanning and the method of processing may be varied. Electro-optical parameters, on the other hand, are those which operate on the video output obtained from an area matching system which optically measures the degree of agreement between preselected shapes and those encountered on the input imagery.

4.1 BASIC MEASUREMENTS USED FOR PARAMETER EXTRACTION

While many electronic and electro-optically extracted parameters have been investigated, many others could have been analyzed for potential bearing on the target recognition problem. This section describes the sources or types of measurements from which we have been extracting the parameters for target recognition. The four different types of measurements from which parameters have been extracted are described below.

The first measurement is the "photographic detail" contained in the viewing aperture. The basic circuit used to measure this parameter produces an output pulse whenever the magnitude of the derivative of the video waveform obtained while scanning the photograph exceeds a predetermined threshold. Thus an output pulse is obtained whenever a steeper than predetermined contrast change is taking place. This basic measurement can be adapted to the numerical indication of many different useful photographic properties of the target area. If for simplicity, we associate the occurrence of an output pulse with a boundary crossing, an output display produced from the intensity modulated display of the output pulses produces an edge enhanced image as shown in Figure 4.2. It is obvious that the direction of the scan affects whether or not a boundary is detected by above threshold video derivative indication. If a boundary is crossed at a steep angle, it is detected. If, on the other hand, the scan line runs parallel to a boundary, or intersects it at a very shallow angle, the magnitude of the derivative will be low and the boundary will go undetected. To avoid this directional sensitivity an isotropic scan has been used to scan every point on the picture in at least two directions, assuring that at least once every boundary will be crossed and detected. See Figure 4.2d. Averaging the output or counting the number of output pulses during frame time is a measure of the edge content or an average of the amount of photographic detail in the viewed area. As such, this property and others, which will be discussed later, can distinguish between target areas which exhibit a large number of edges from those that exhibit only a few. The Detail Circuit produces an output pulse whenever the magnitude of the video derivative exceeds an adjustable threshold. The threshold control permits setting the magnitude and sharpness of the transition that will be detected. The output pulse is short compared to a single sweep of the scan and compared to a single element of detail on the picture. This output waveform serves as the input to other parameter extracting circuits.

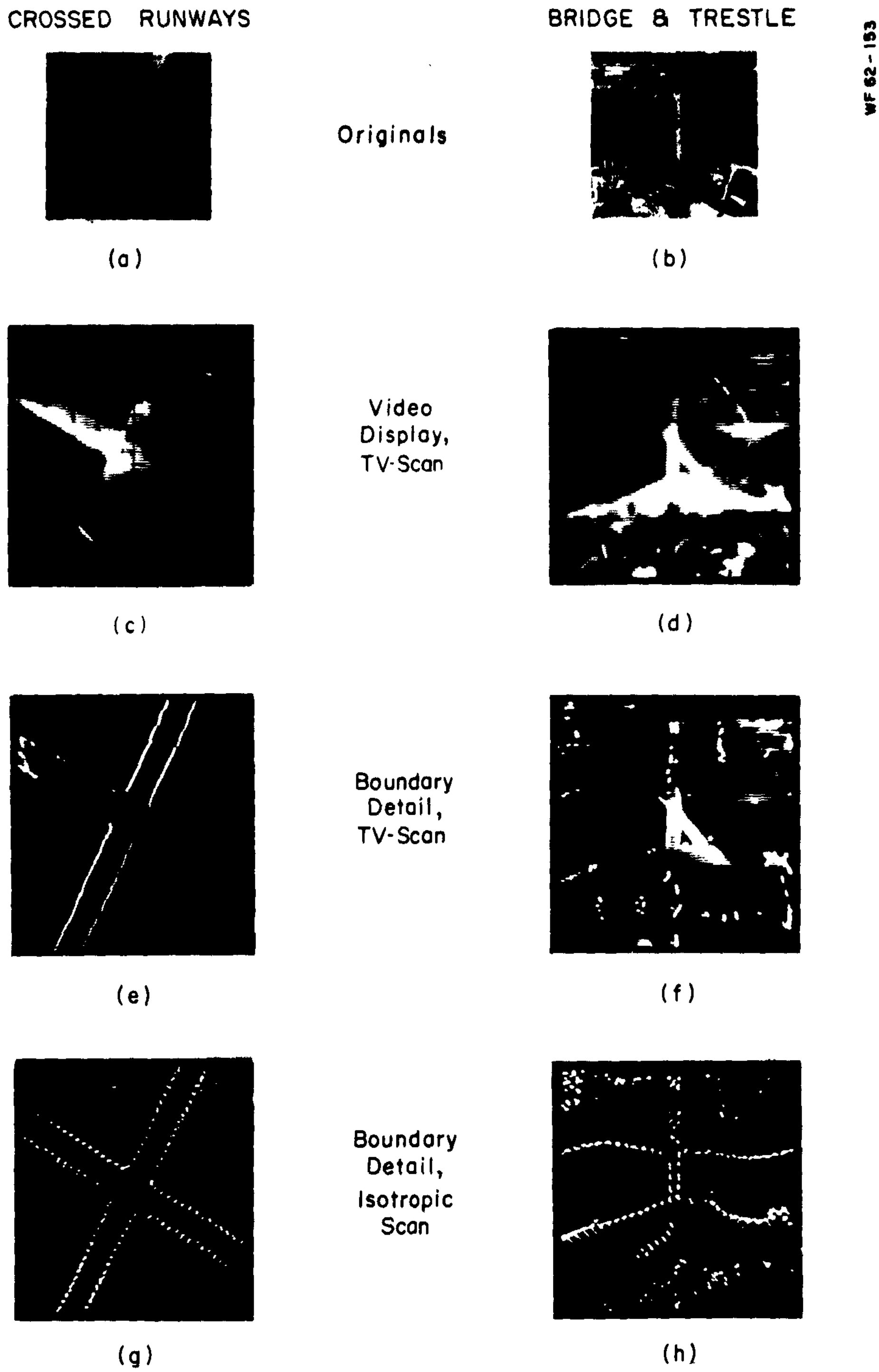
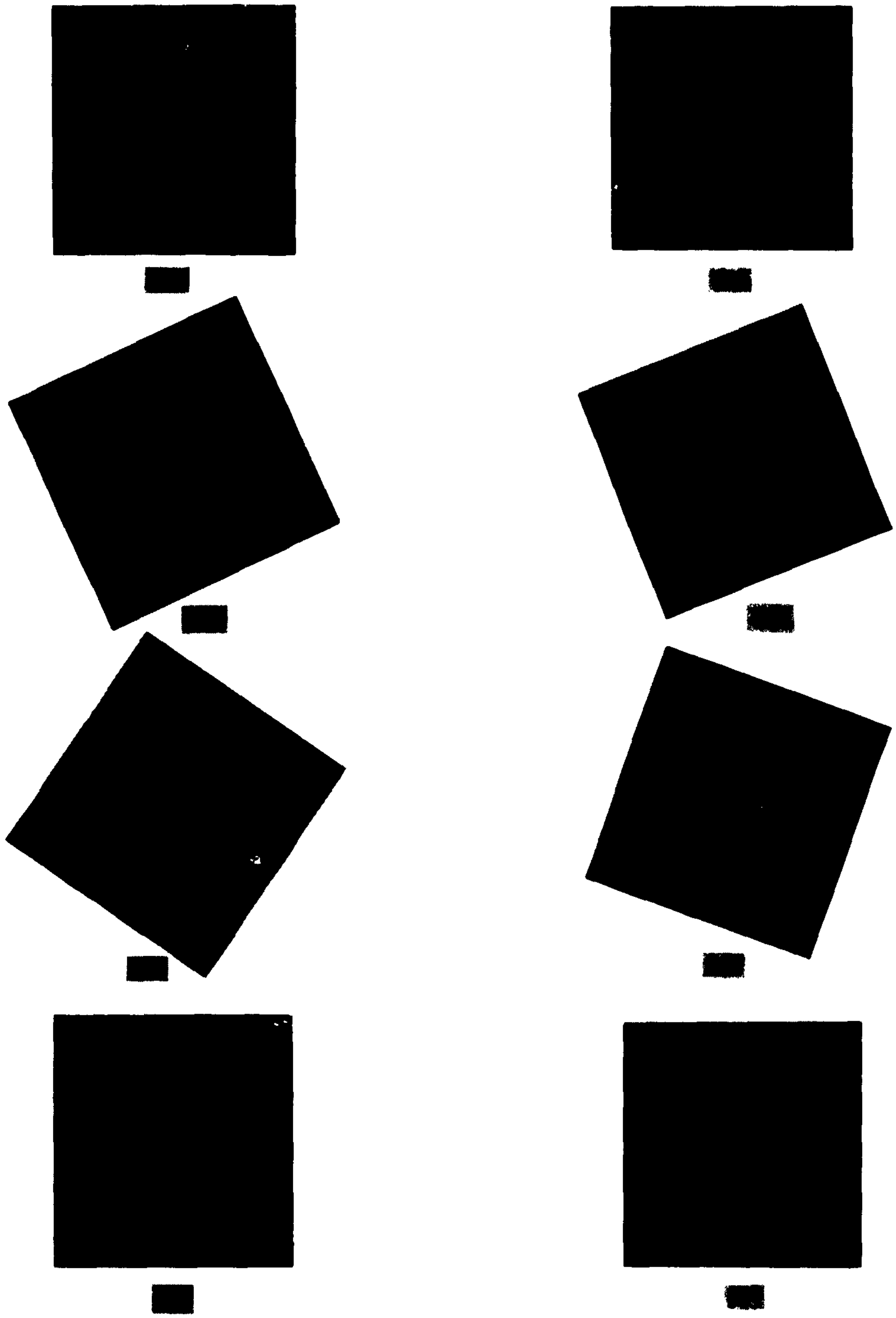


Figure 4.2 Detail Extraction by Stationary-TV and Isotropic Scans

The second basic measurement utilizes the sensitivity to direction of the above described basic measurement and of other measurements to be described later.to detect target characteristics that are not rotationally constant. A television scan is used and the entire scan frame is rotated to scan the area sequentially at all angles. (See Figure 4. 3). The direction dependent output of this measurement and of those to be described later are utilized to determine the number of axes of symmetry, the angles subtended by principal lines, the asymmetry and irregularity of the target texture, and other properties of interest which will be described later. An electromechanical resolver supplies the rotational signal components that are added to the basic TV scan to produce a rotating scan.

A third useful basic measurement consists of a measurement of the uniformity of spacing of successive detail pairs. In particular, the Uniformity of Photographic Detail is measured by a circuit which is designed to measure the average spacing between objects or the size of objects within the scanning area. The circuit determines the difference between the average boundary crossing interval and the latest boundary crossing interval. The difference is then averaged over the total frame time to obtain a measure of the average magnitude of the deviation in spacing between objects located throughout the frame as compared to the average spacing between objects in the viewed area. This parameter is thus able to measure the uniformity of texture in the direction perpendicular to the lines of scan. A ramp generator of constant slope initiated at the occurrence of a boundary crossing pulse and reset at the occurrence of the next boundary crossing pulse, converts the spacing between successive boundaries to a triangular waveform whose height at the apex of the triangle is proportional to the last boundary crossing interval spacing. The triangular waveform is sampled at its peak and held until the next sampling period, producing a rectangular waveform whose height indicates the interval between the last pair of boundary crossing pulses. The operation of the degree of uniformity circuit may be seen in the drawing at the bottom of Figure 4. 8. If the successive boundaries are equally spaced, the peaks of the triangular waveforms will be of equal height and the resulting step-wise waveform will be a steady dc voltage, thereby indicating a uniform spacing between successive boundary crossings. As the spacing between successive boundary crossings becomes increasingly non-uniform, this irregular spacing of terrain features can be measured by the increased ac component of the rectangular waveform. The dc component indicates the average spacing between objects. Since the output of this circuitry is highly direction sensitive, this property can be used to advantage in conjunction with the rotating television scan described in the preceding paragraph. It can readily be seen that the

[redacted]



[redacted] Rotating- TV Scan

rotational output would be quite different for urban areas having city blocks with a small ratio of length to width as compared to industrial areas containing long rectangular buildings.

A fourth basic type of measurement that can be performed on the area under observation is the measurement and observation of the degree of agreement (Degree of Area Match) between portions of the input image and stored reference shapes in the library. Electro-optical area matching techniques described in the following section have been investigated and a method has been developed to extract the average content of a given shape regardless of the orientation, magnification and position of the input image as well as to extract parameters that make optimum use of the directional sensitivity of the basic area matching system. The rotational sensitivity can be used to determine the angle between straight lines that have previously been detected by the equipment. For example, the presence of wide bars 30° to 60° apart serves as a useful clue or parameter for the detection of airport runways. Note that the area matching system is basically a computation of a two-dimensional correlation function - a correlation between the input imagery and the image in storage.

4.2 AREA MATCHING

Consider the optical system shown in Figure 4.4 in which a point source is collimated by a lens L1. The ideally uniformly distributed light intensity that exists immediately to the right of lens L1 is modified by the area matching mask. Lens L2 focusses the non-uniformly distributed beam of light into a point. The light intensity distribution between lens L2 and the focal plane corresponds to a shape determined by the transmission characteristics of the area matching mask positioned between the two lenses. In the example shown, the light distribution is in the shape of a horizontal bar of constant length to width ratio whose size is inversely proportional to the distance from L2. The light collected by the photocell located in the focal plane, is proportional to the average transmissivity of the image over the region of the negative illuminated by the shaped light source. Assume, for simplicity, a negative containing only binary values of light transmissivity. The output of the photocell is proportional to the degree of overlap between the transparent portion of the picture and the image of the bar. No decrease in observed output results from a negative that is transparent over an area larger than the image of the horizontal bar. The output is reduced, however, if the negative is not transparent over this entire rectangular area. Now let us assume that a second optical channel identical to the first exists in which

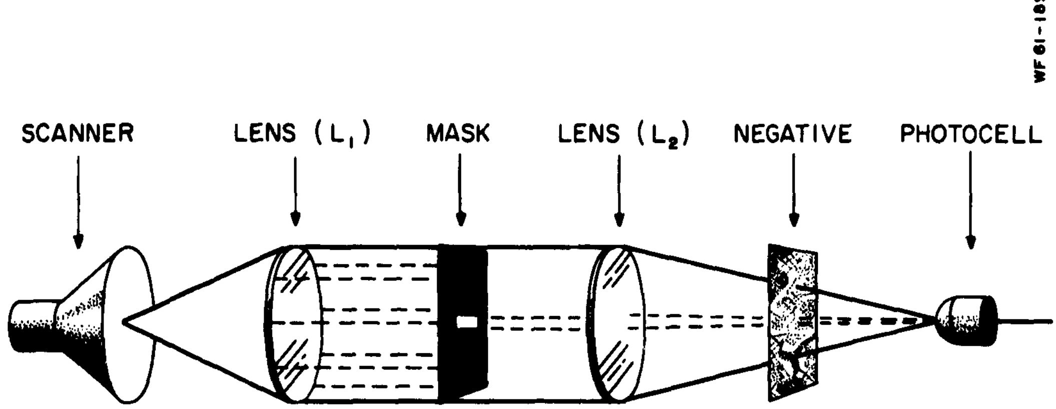
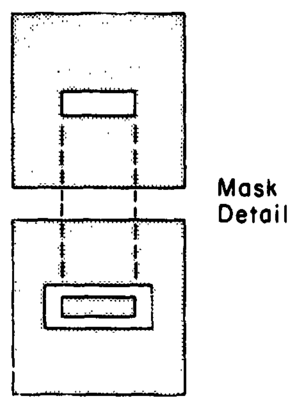


FIGURE 4.4. First Optical Channel



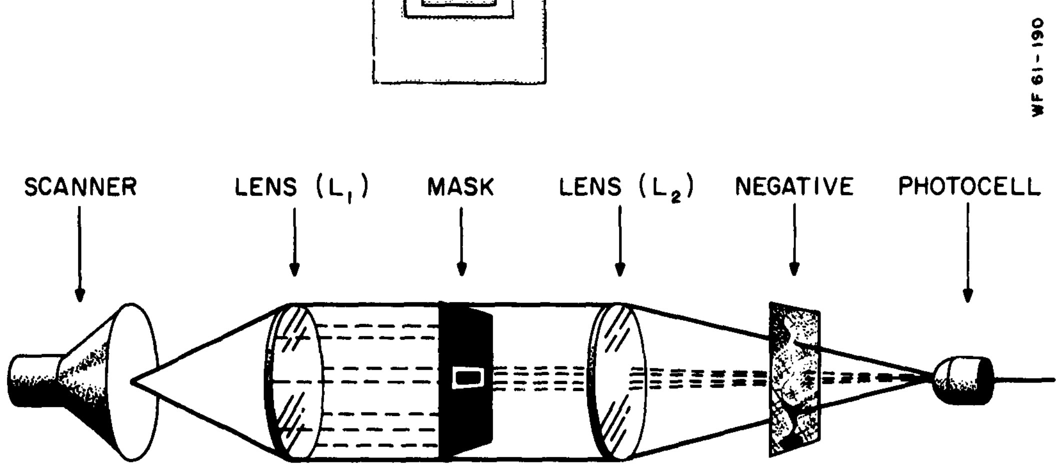


FIGURE 4.5. Second Optical Channel

the negative is an exact duplicate of the one in the first optical channel. The optical mask shown in Figure 4.5 provides a light intensity distribution in the plane of the negative that has a non-zero value only in a small region immediately surrounding the area illuminated by the mask in the first optical channel. The output of the second optical system is proportional to the transparent area of the negative in the region illuminated by the light passing through the second optical mask. If the electrical output of one optical channel is subtracted from the other, and the gain of the two electrical outputs normalized, a maximum output is obtained when the picture contains a transparent region that is an exact image of the illuminated region in the first optical channel and is at the proper location and orientation. This is illustrated in Figure 4.6a where the horizontally cross-hatched area is illuminated by the first channel and where the vertical cross-hatched area is illuminated by the second channel. Imagine the hypothetical situation where transmission of the negative in the heighborhood that is illuminated by the two optical channels is as shown in Figure 4.6b. The difference in the electrical output of the two channels is proportional to the difference between areas A and B. It is readily appreciated that the maximum output from this system is obtained when the light transmitting portions of the image are an exact match in scale, location, and orientation of the horizontally cross-hatched area illuminated by channel one. Altering the positions of the point sources of light in Figures 4.4 and 4.5 simply translates the mask images to a new region of the negative. Since we are interested in the presence in the film of the geometric shape portrayed by the mask regardless of relative orientation in the image plane, we must successively and simultaneously rotate the two masks to extract the parameter in question in a manner that is substantially rotation insensitive. We must thus observe the electrical output of the system over the period of time that corresponds to a 360° rotation of the pair of masks. If, as is the case for the SATRD, we are interested in the "amount of the parameter per unit area" in the photographic image, we must integrate the electrical output of the device over a period of time necessary to sweep out the areas in question with the point source of light while rotating the pair of masks.

Analog integration of the electrical signal over all mask angles may result in a large output if only partial matches occur, in the event such partial readings occur for a large number of mask orientations. This can be avoided if a binary threshold is employed to give a "match achieved" pulse whenever the difference signal lies above the threshold. These pulses are then counted for one period of revolution of the masks.

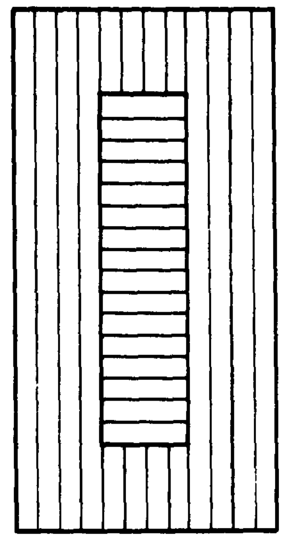


FIGURE 4.6a. Area Illuminated by Two Optical Channels

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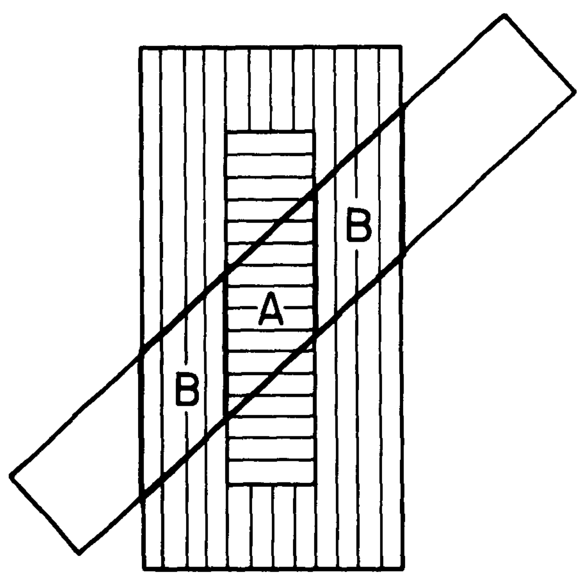


FIGURE 4.6b. Regions of Transmissivity For Two Channels

The two optical channels are combined into a single system by using two different colored regions in the area matching mask in conjunction with two separate photocells equipped with appropriate colored filters. The resulting optical system is shown in Figure 4.7.

For further analysis of the basic measurement waveforms and to extract well-defined statistics of these waveforms, circuitry capable of obtaining first order probability densities of analog voltages has been constructed. The input to the circuitry is an analog voltage which may either represent the video waveform, or a waveform representing the distance between successive boundary crossings, (Figure 4.8) or a waveform indicating the degree of area match that exists between an input image and a stored shape. The output of the circuit is a constant voltage whenever the input waveform falls within a range $\pm\ \delta/2$ of the threshold voltage τ. Both the threshold, τ, and the range $\pm\ \delta/2$ are adjustable. A one-shot multivibrator operating on the output of the above circuit indicates a "success" by producing a single pulse for each "event" or voltage falling within the preselected range. See Figure A.11. By counting the number of successes (actually performed by means of an integrator) and successively advancing voltage τ, it is possible to plot the probability density of a waveform. Further, sensitivity of the probability density to the direction in which the scan lines are oriented can be used to detect important target features. Although the circuitry has been completed, because of time and fund limitations, parameters extracted from this circuit have not been incorporated in the set of measurements on which further analysis was carried out.

4.3 AREA MATCH MEASUREMENTS

Data using the basic measurements described has been collected on a selection of photographs that will be described later. From these data a selected set of parameters was obtained and the set was subjected to computer-aided analysis to determine the recognition capability of the chosen parameter set. Partial results obtained in some early experiments are also described in this report.

During checkout of the area match electro-optical system, a droop in the output of the difference amplifier became evident. No difficulty had been experienced during the extraction of the electronic parameter data, since gradual video changes were effectively filtered out as part of the

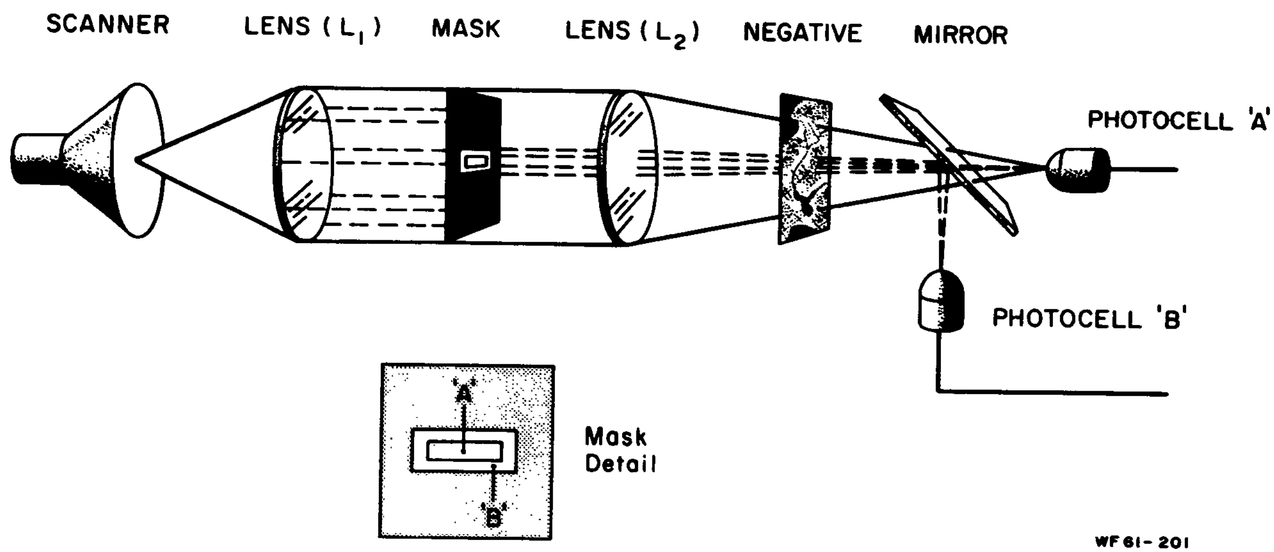
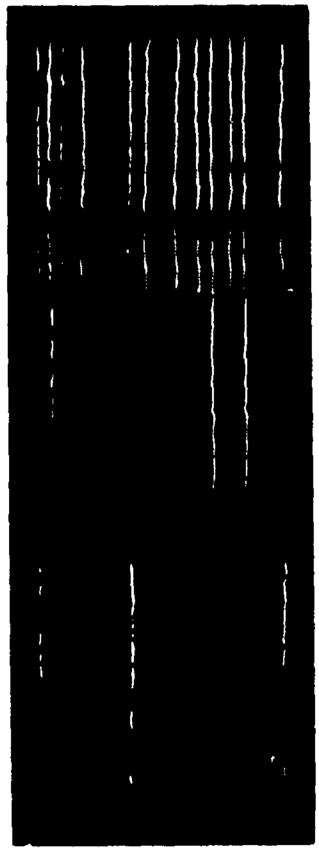


FIGURE 4.7 Combined Two Channel Optical System



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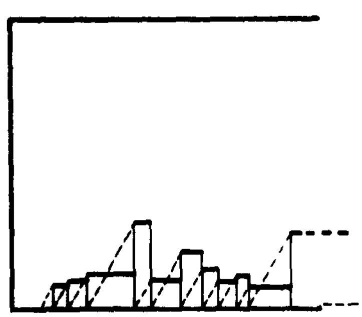
UNPROCESSED VIDEO

DISPLAY OF BOUNDARIES WITH SELECTIVE SPACING

DISPLAY OF BOUNDARIES WITH INCREASED SPACING



DISTANCE BETWEEN SUCCESSIVE BOUNDARIES
(Degree of Uniformity Circuit)

FIGURE 4.8. Voltage Range Indicator Operating on Degree of Uniformity Waveform.

boundary detection process. To correct this problem, the optical system above the film plane was redesigned to place the photomultipliers in the image plane of the mask holder, where previously the photomultiplier had been located in a second image plane of the flying spot scanner tube face. This modification completely eliminated output variations due to random variation in the sensitivity at different points on the photomultiplier tube cathodes. Two of the three lenses in the light collection box were eliminated and the entire box was lowered to prevent vignetting of the light beam. These changes improved linearity for area matching by 35 percent and increased by 40 percent the amount of light collected by each of the photomultipliers.

Tests were run on the targets of Figure 4.9 consisting of parallel straight lines of several widths and a number of rectangular grid patterns. A line mask was scanned systematically across each target with the mask continuously rotating at a rate of 2.3 degrees between successive rasters to produce the "degree of area match vs mask angle" curves of Figure 4.10. The size of the mask image in the film plane was varied over a 4:1 range by adjusting the position of lens L2 of Figure 5.1 with the aid of the focussing handwheel (Figure A.14). After recording the output during one rotation of the mask, lens L2 was repeatedly lowered and the output was recorded at eight calibrated lens settings. In this manner the size of the projected mask image was varied over an 8:1 range for each of the line and grid targets.

The ability of a rotating mask to detect the principal axes of symmetry is apparent when, for example, the output of straight line sample X3 is compared to that of the grid X4; in the former the output peaks are at 180 degree intervals, while in the latter the peaks are at 90 degree intervals. Sample X8 displays uneven peaks at 90 degree intervals, pointing to the rectilinear nature of the grid pattern.

Following the above tests, a number of masks were chosen for use with selected examples of aerial photography. The photos of 4.11 and 4.12 illustrate the ability of a circular mask to detect oil tanks and of the line mask to detect roads and bridges. The two lower photos of Figure 4.11 compare the selective effect of a line mask, with its ability to detect lines (or roads) of a specific width range, versus the broad selectivity of a "boundary" mask, which is characterized by the ability to detect lines (or boundaries between areas of different color) of any width.

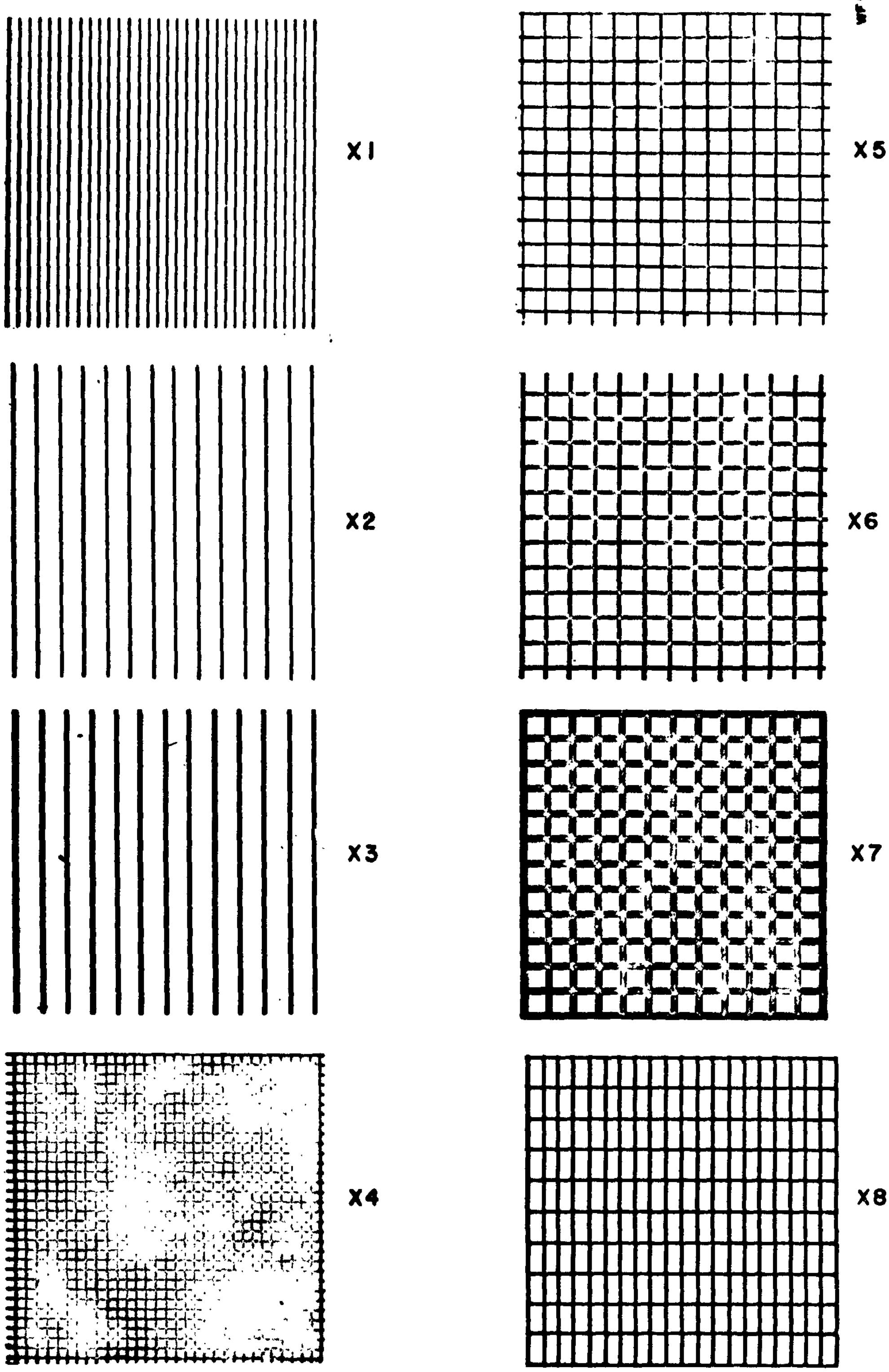


FIGURE 4.9. SAMPLE TARGETS - LINES AND GRIDS

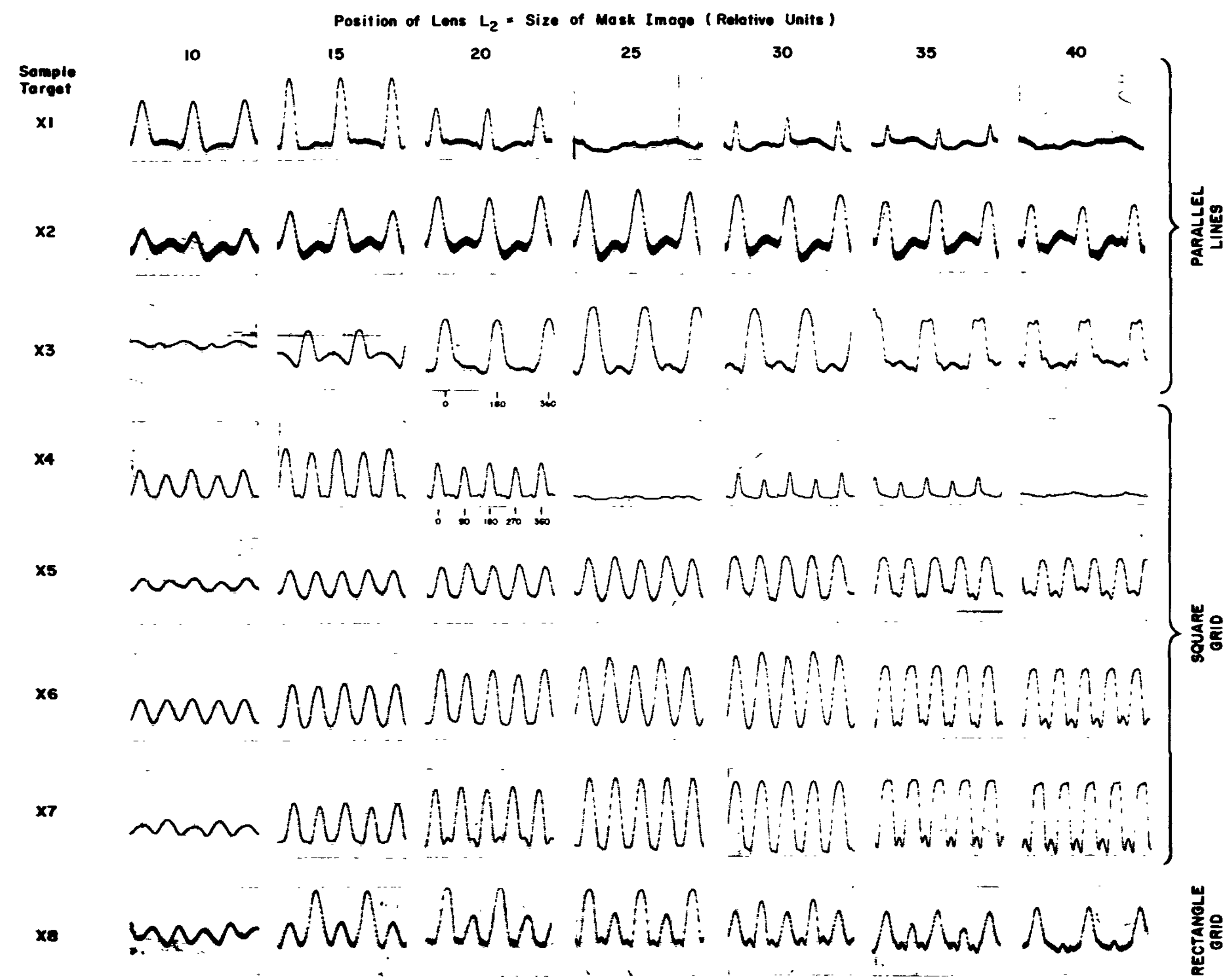


Figure 4.10. DEGREE OF AREA MATCH vs. MASK ANGLE

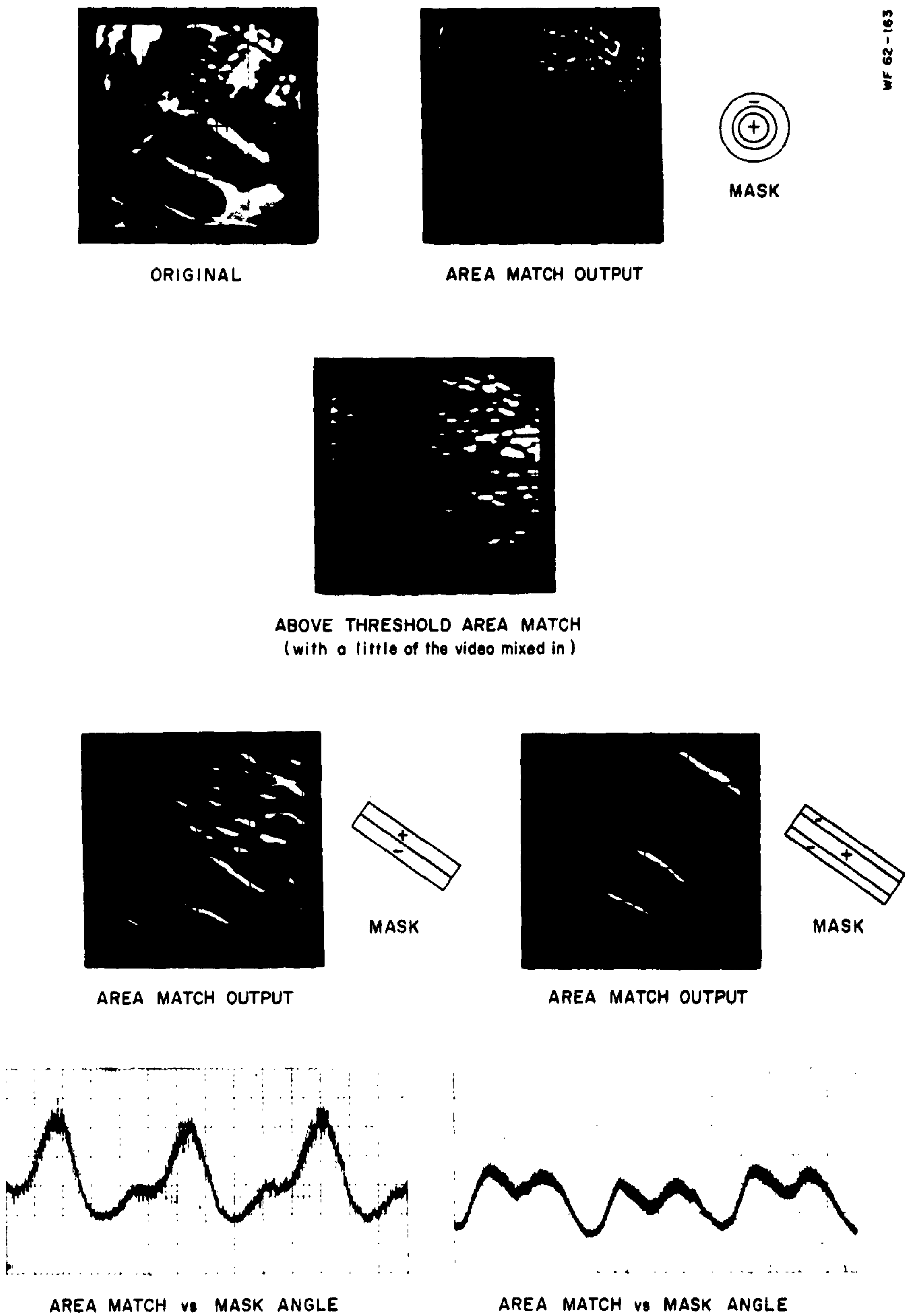


FIGURE 4.11 Typical Area Match Outputs

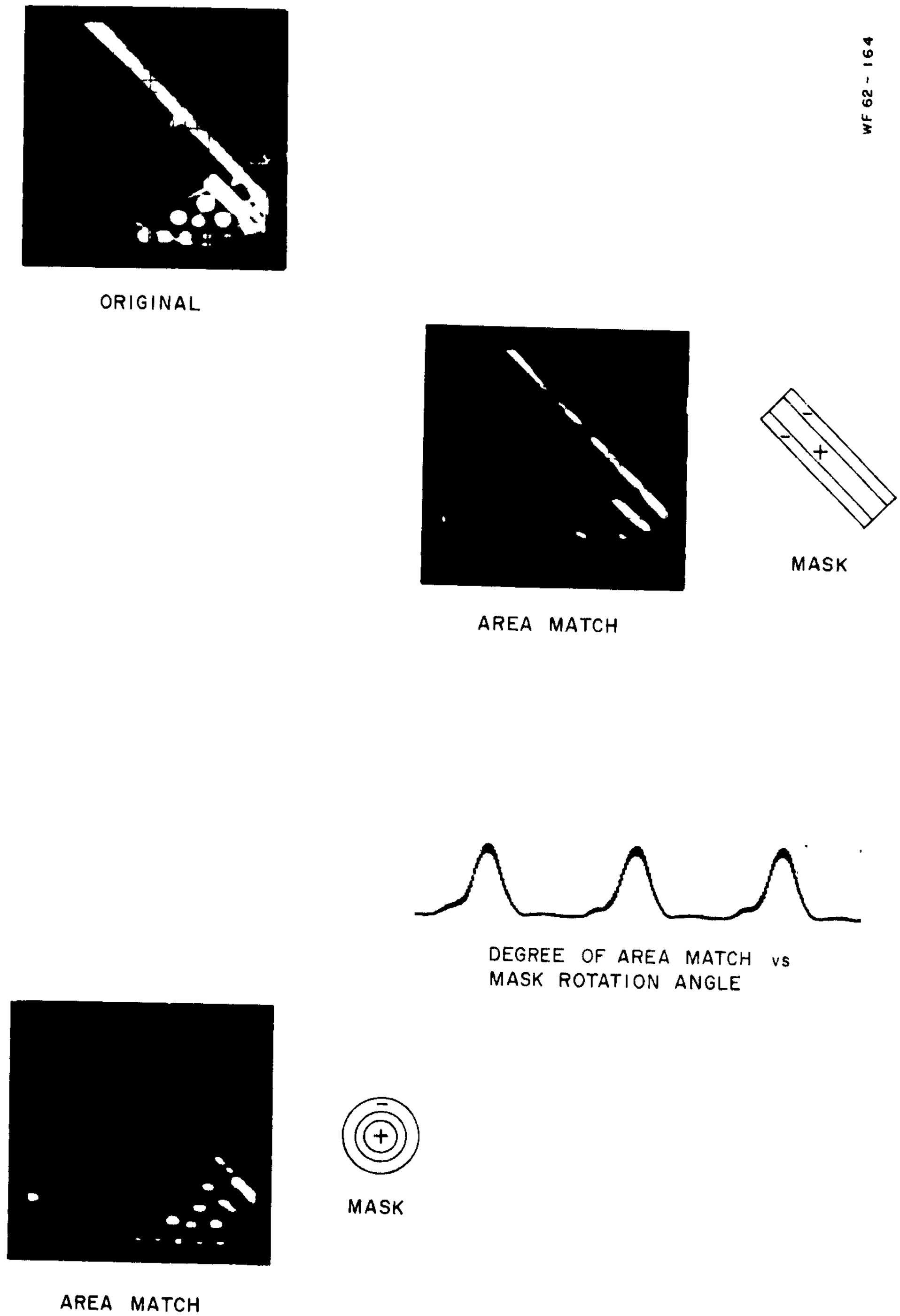
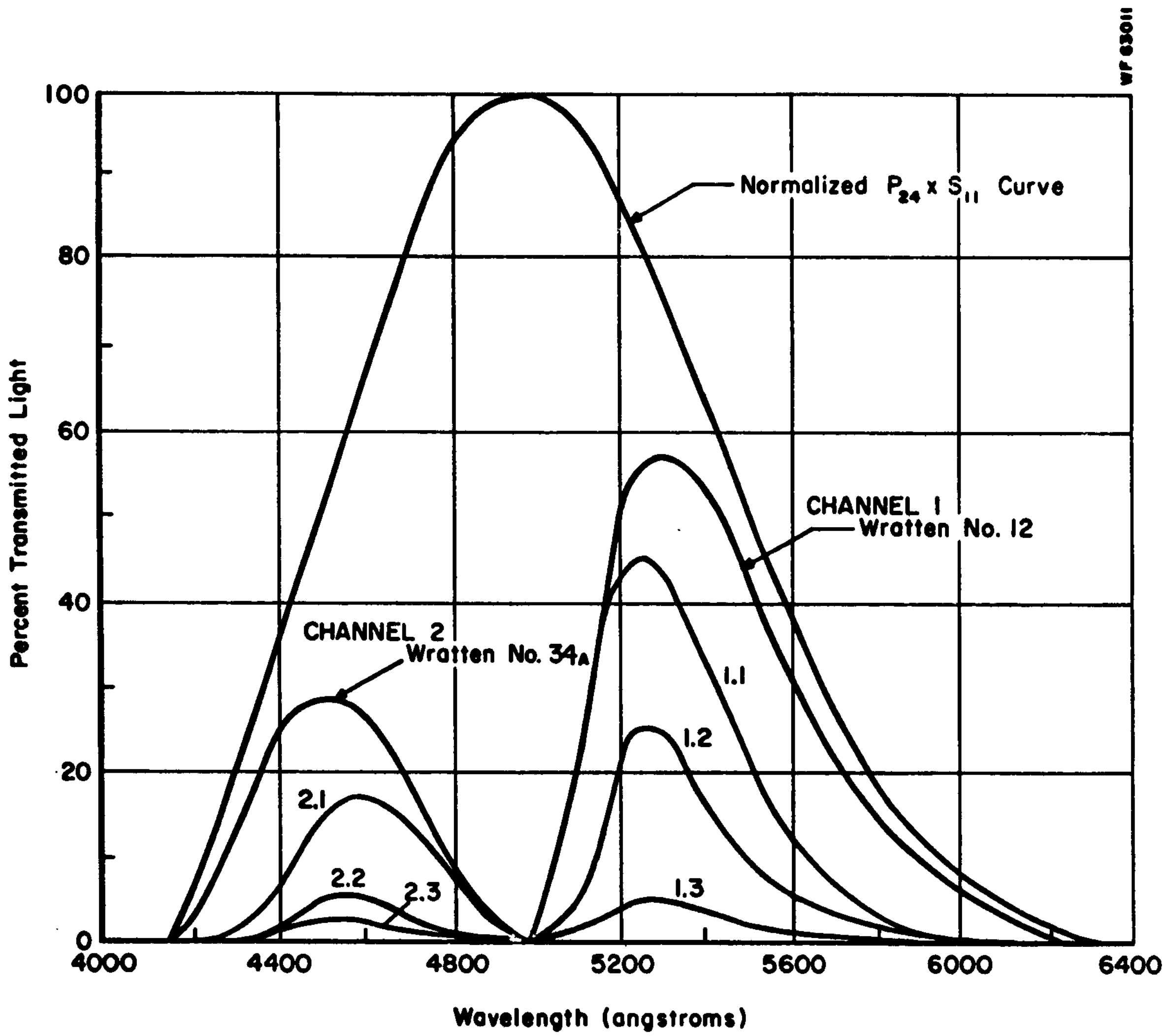


FIGURE 4.12 Typical Area Match Outputs

Before proceeding with the extraction of parameters from the entire group of 150 samples, an initial run was made on a group of 20 samples (2 each of 10 classes) selected at random from the master set. The recordings, in nearly all instances, displayed moderate peaks at 180 degree intervals. Based on the result obtained with the sample lines and grids of Figure 4.9, the peaks were not entirely unexpected, but their appearance in targets that did not contain lines indicated that another effect was intruding. The difference among classes was still sufficient to insure that area match parametric data collected from all 150 samples would improve the previously reported performance of the SATRD, but the gain would fall short of what had been expected.

The difficulty was traced primarily to inadequate light output. Less than 0.5 percent as much light was available for area matching as for electronic parameter extraction. Refer to Figure 4.13. After passing through the color filters in the mask, the light available in channel no. 1 decreased to 18 percent and that in channel no. 2 to 8 percent. The color filters in front of each photomultiplier cut the light further in each channel to 8 percent and 1.5 percent respectively. The beam splitter divides the reflected and transmitted light in the ratio of 4:1 thereby equalizing the available light in the two channels to 1.6 percent and 1.2 percent. (Final equalization is performed electronically.) Each section of the circle mask (Figure 4.14) can intercept no more than 50 percent of the total light passing through the mask holder, resulting in a decrease to 0.8 percent and 0.6 percent in the light originally available from the flying spot scanner. Most other masks, because of their overall outline, will block an additional 20 to 90 percent of the available light.

An increase in light output from the flying spot scanner and/or an improvement in the "use factor" was imperative before the device could be used with aerial photography, with its typically low contrast and high background density. An increase in light output could be obtained by modifying the high voltage supply. Replacement of the conventional metallized beam-splitting mirror with a multi-layer dichroic beam-splitter would produce a factor of 10 gain, due to the ability of a dichroic mirror to reflect one portion of the light spectrum while transmitting another portion of the spectrum, and thereby permitting removal of the set of color filters from in front of each photomultiplier. Further improvement might be achieved by construction of dichroic area-match masks, but the cost would be high for an experimental device.



	Available Light...			
	Channel 2		Channel 1	
After passing through mask	2.1	7 %	1.1	18 %
After passing through 2ND filter	2.2	1.5 %	1.2	8 %
Effect of 4:1 beam splitter	2.3	1.2 %	1.3	1.6 %

FIGURE 4.13. Illumination Usage in Two-Color System

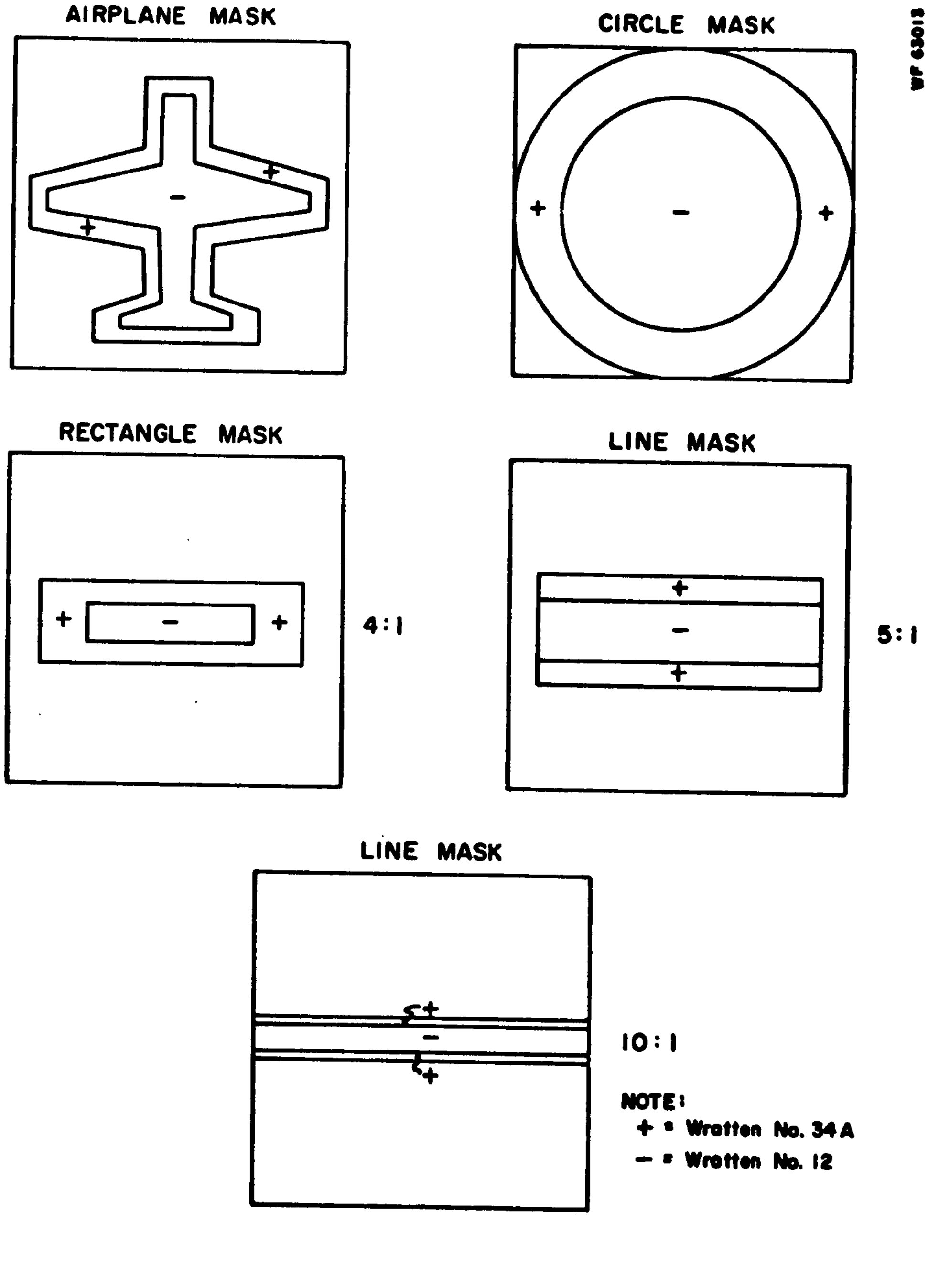


FIGURE 4.14. Two-Channel Masks

With time and funds running low, a modification program would result in an improved device but there would be insufficient time to complete the extraction of the area match parameter data on all of the 150 strategic target samples. No time would be available for performing any experiments with the SATRD on tactical imagery. Since the multi-parameter approach had already been proven while working with the electronic parameters, the decision was made to concentrate our remaining time and effort on experiments related primarily to tactical targetry. The SATRD was to be used within its existing capability and without further modification.

With strategic targets it is often desirable to use a building-block approach and to search for elements such as lines, T-shaped crossings, X-crossings, acute-angle crossings and rectangular shapes. Tactical targets such as warships, army tanks and aircraft generally must be searched for as an entity. The associated problems require detailed analysis rather than the extraction of masses of data. For example, it is to be expected that a given mask will display a maximum output when the mask agrees exactly in size and in shape with the target, if at the same time the target possesses infinite contrast with respect to the background. Nevertheless, it is necessary to understand the exact relationship that exists between mask, target size, target shape, target spacing, and background density before detection and decision making techniques can be made effective and reliable over the full range of these variables likely to be encountered in tactical and strategic aerial photography. To this end, a study was made to determine the theoretical and the experimental factors influencing the use of area match parameters for target recognition.

4.3.1 Comparison of One-Channel and Two-Channel Masks

A comparison of the waveforms to be expected when single-channel and two-channel masks are scanned across several simple targets is presented in Figure 4.15. A one-channel mask is shown scanning across an opaque target on a clear background in Figure 4.15a. Since the mask width is exactly equal to the width of the target, a triangular pulse is generated whose base is twice the width of the target. The waveform generated by a two-channel mask when scanned across the same target is also shown in Figure 4.15b. This waveform is more complex, having two negative peaks of one-half the amplitude of the positive peak, and a positive peak of twice the slope and one-half the width of the peak produced by the one channel mask.

The waveforms of Figures 4.15b are generated when each mask is scanned across a target with a transmittance of 50 %. The two waveforms are identical to those in Figure 4.15a except for the amplitudes having decreased by a factor of two. So far, there seems to be no major advantage to the use of two-channel masks in preference to one-channel masks.

If a large dark area is scanned the waveforms of Figure 4.15c are produced. With a threshold of plus 0.5, the two-channel mask differentiates effectively between specific matching targets and targets that merely blanket the mask outline while possessing no other specific relationship to the mask.

In typical aerial photography neither the average contrast nor the dynamic contrast, that is, the variation in contrast in going from one small neighborhood to another, remains constant over even a single frame. This is illustrated in the example of Figure 4.15d, in which the background density varies from zero to 0.5 and the target contrast varies from 0.5 to unity along a single scan line. If successful recognition is determined by counting all outputs equal to or above an arbitrary threshold, for example, 0.5, then the one-channel mask will incorrectly indicate the presence of five targets, while the two-channel mask will correctly point out the three targets. Greater electronic sophistication than the selection of a threshold can improve the recognition performed by either type of mask. However, the constant zero baseline and the narrow width of the peaks obtained with two-channel masks, as contrasted to the baseline shift and wide peaks obtained with single-channel masks, continue to favor the former.

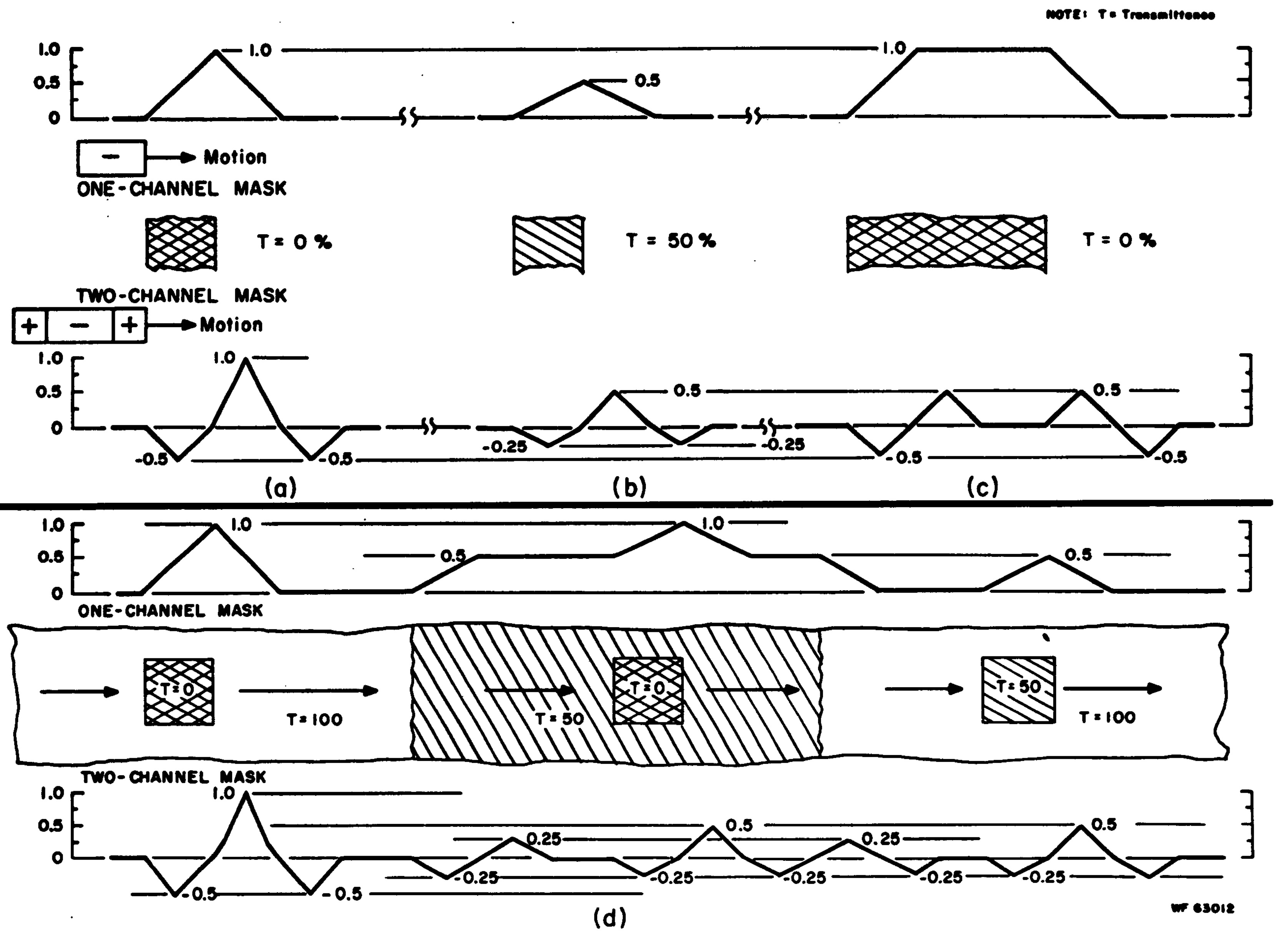


FIGURE 4.15. Comparison of One-Channel vs. Two-Channel Mask Outputs

In general, the two-channel mask is more effective than the one-channel mask in distinguishing between a desired target and another target whose shape does not agree with the mask, although the target outline totally envelops the mask image. Nevertheless, the fact remains that mask output is a function of the target contrast, as well as of the correlation between the target and mask shapes.

The effect of target size on area match output is dealt with in the next section, while Section 4.3.3 presents a procedure that will permit effective decision-making despite variations in dynamic contrast.

4.3.2 Mask Output As a Function of Target Size

This section deals with a study to determine over what range of target sizes a mask will successfully distinguish between targets similar to the mask and targets of other classes. Theoretical and experimental results are presented for the group of masks of Figure 4.14. Each mask exactly matches one of the group of 35 targets illustrated in Figure 4.16, in which seven sizes of each of five classes are represented.

Shape correlation or area-match output is also dependent on the relative angular orientation of the mask and target. It therefore becomes necessary to scan the area under investigation at many different angular orientations of the mask; in the SATRD the scan raster is automatically rotated 2.3 degrees between successive rasters to assure adequate angular coverage within a reasonable period. However, to limit the investigation reported in this section to the most significant data only, the masks and targets have all been orientated in the same direction.

A plot of the experimental peak output obtained when an "airplane" mask is scanned across a group of seven airplanes that vary in size over a 7:1 range is presented in Figure 4.17. As expected, a maximum output is obtained when the mask and the airplane target match exactly, and the output decreases when the target is either smaller or larger than the mask.

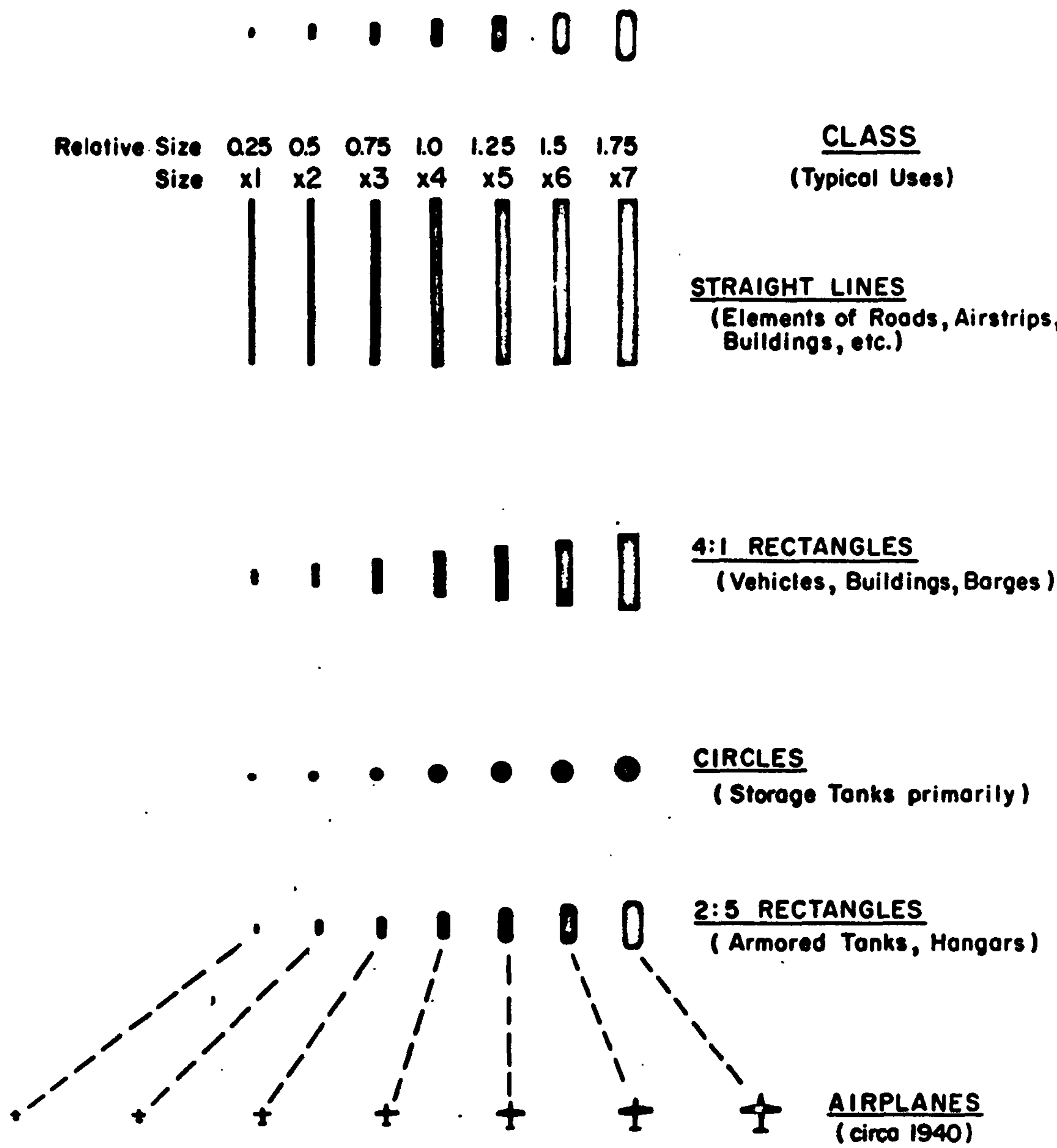
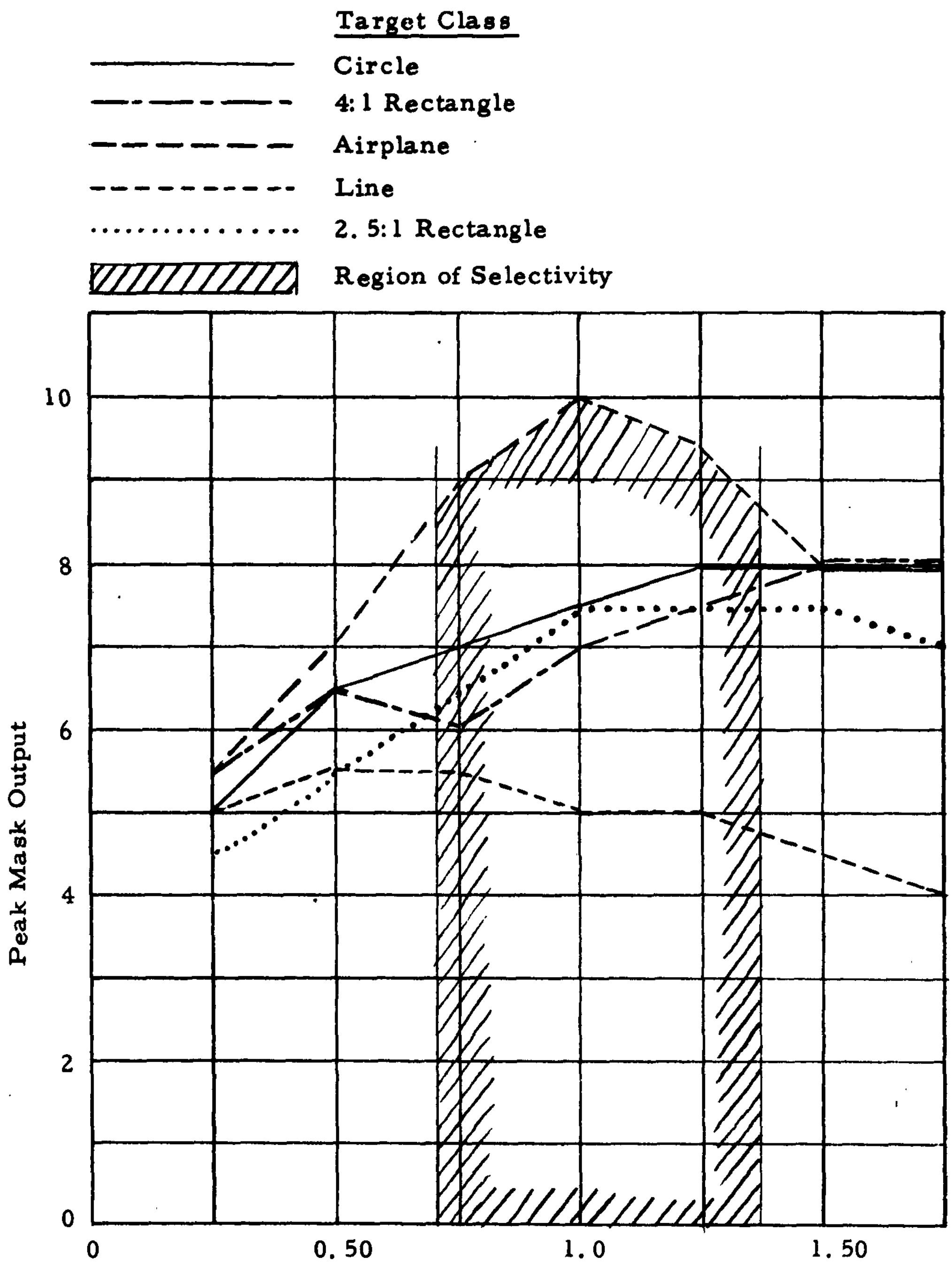


FIGURE 4.16 Sample Target



(Experimental Results)

Figure 4.17 - Airplane Mask Output for Five Target Classes

Figure 4. 17 also contains plots of the output of the airplane mask when it is scanned across a similar 7:1 size range of the four remaining target classes of Figure 4 16. Note that the output of the airplane mask, when scanning the rectangle and circle targets, does not display the symmetrical fall-off exhibited when scanning airplane targets. A detailed consideration of the geometrical shapes involved reveals that this result is to be expected. The region in which an output for the correct class is at least 10 percent greater than that achieved with any other target class has been labeled, "region of selectivity". Thus, the airplane mask can distinguish airplanes from rectangles, circles, and lines over a size range of nearly 2 to 1, or 70 to 137 percent of the nominal size of the mask. When searching for airplanes that vary in size over a larger range than can be effectively recognized by a single mask, additional masks will be required. Some improvement may be obtained by designing one mask to correspond to the shape of the smaller swept-back fighter planes and another to correspond with the larger medium and heavy bomber types.

The curves of Figure 4. 18 represent the output obtained when a 4:1 length-to-width ratio rectangle-mask is scanned across the same group of 35 targets. While the output curve for a 4:1 rectangle mask scanning a group of 4:1 rectangular targets is similar to the curve in Figure 4. 17 for an airplane mask scanning a group of airplane targets, the remaining outputs vary over a wider range than those in Figure 4. 17. The "region of selectivity" occupies a range of approximately 80 to 118 percent of the mask size. The greatest difficulty in making a selection between target types is for rectangles that vary only in aspect ratio, e. g. , 5:1 as compared to 4:1. For example, if we are to distinguish between armored tanks and military trucks, which exhibit only minor differences in shape, we shall have to use separate masks for each. However, if we are interested in the general class "vehicles", effective selection over a size range of 70 to 138 percent or 2 to 1 can be achieved. The added region of selection has been labeled "secondary region of selectivity", that is, the region which will permit separation between classes but not necessarily between subgroups of a single class, e. g., armored tanks, troup carriers, or tank trucks. It becomes apparent that only when it is necessary to separate targets of similar shape is it necessary to sacrifice the wide range of selection obtainable by a single mask.

The result of using a circle mask with the group of 35 targets is presented in Figure 4. 19. This mask, of course, is most useful for recognizing oil tanks and similar storage vessels. The "region of selectivity" extends from 87 to 150 percent of mask size, or somewhat less than a range of 2 to 1.

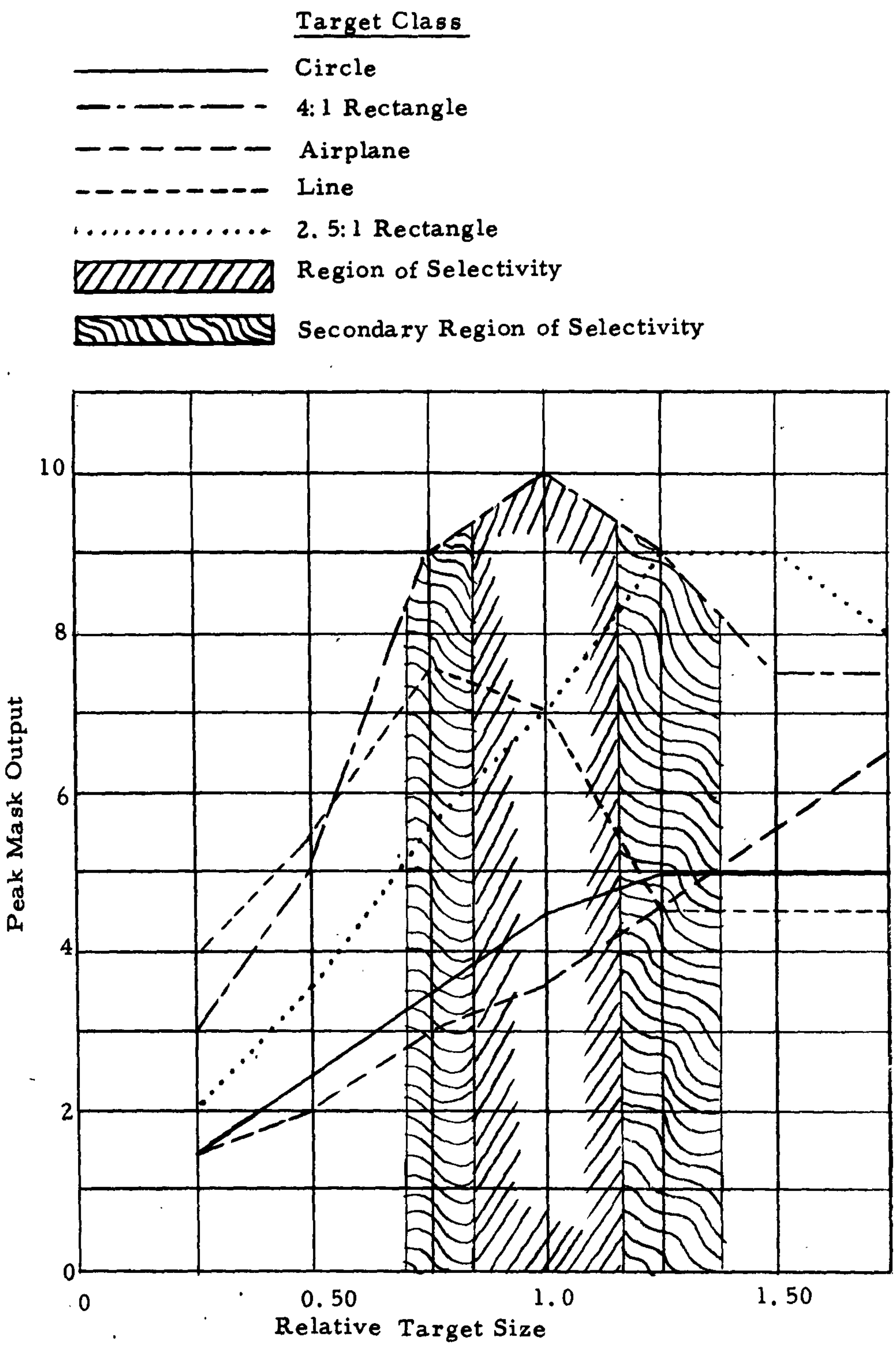


Figure 4.18 - (Experimental Results)
4:1 Rectangle Mask Output For Five Target Classes

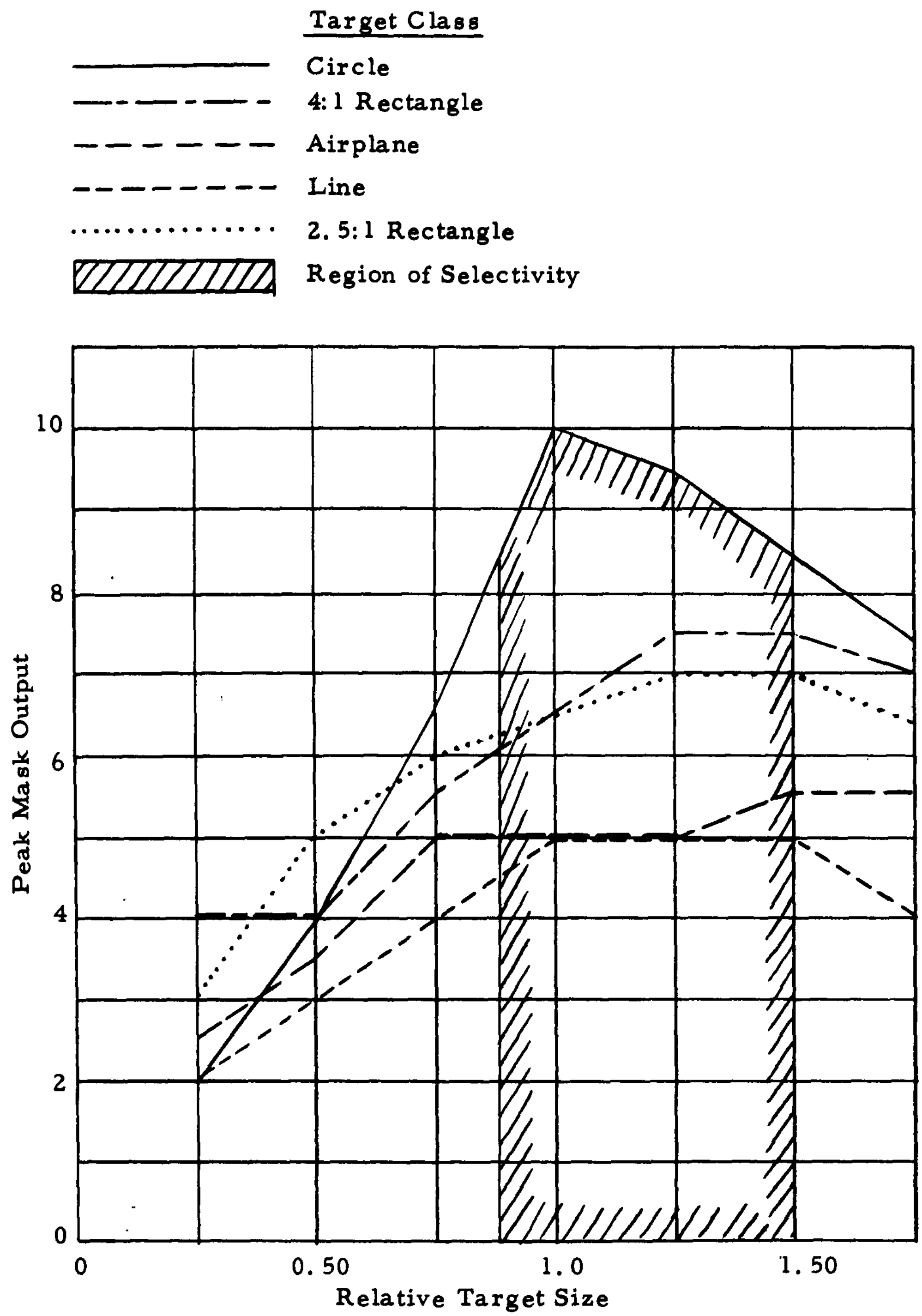
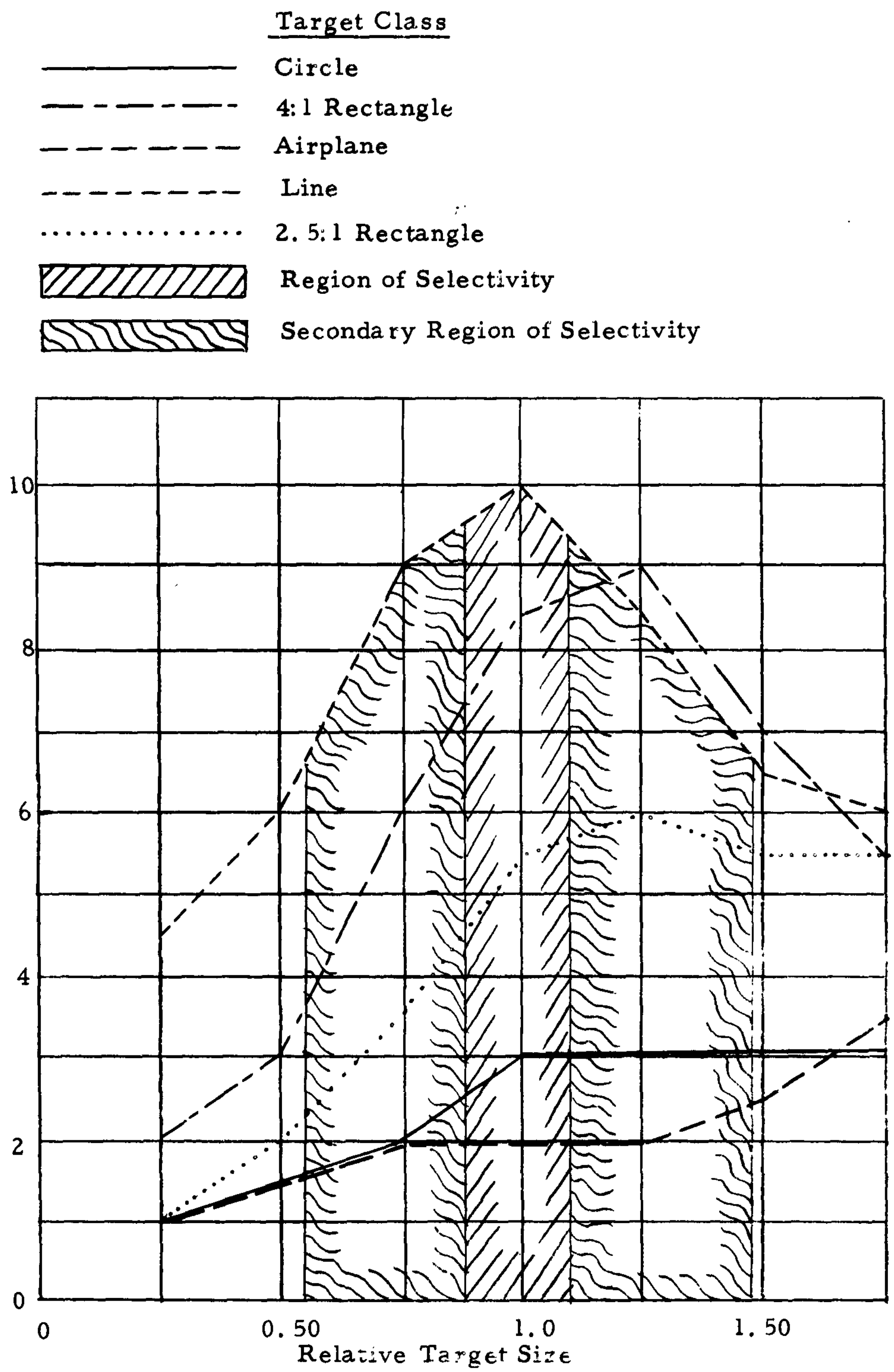


Figure 4.19 - (Experimental Results)
Circle Mask Output for Five Target Classes

A line mask with an aspect ratio of 5:1 was used to obtain the data of Figure 4.20. The close similarity between the 5:1 aspect ratio of the line mask and the 4:1 ratio of the rectangle mask limits the "region of selectivity" to the range from 88 to 110 percent. Because of a limitation on the available light output from the SATRD, the experiments performed were limited to masks with a length-to-width ratio of 5:1 or less. With an increase in light output, a line mask of 10:1 or even larger aspect ratio is feasible. With such a mask the selectivity between lines and 4:1 rectangles can be as great as that presently obtained between lines and 2.5:1 rectangles. The separation of 4:1 rectangles from 5:1 lines or 5:1 rectangles is necessary only for the separation of subclasses. For the separation of classes, the region of selectivity may be extended to include a large "secondary region of selectivity", with a total range of selection extending from 55 to 147 percent or a range of 3 to 1 in size. It is useful to note that naval ships, in addition to size and shape differences, display typical length-to-width ratios of 5.5:1 to 8:1 for battleships, 9:1 to 11.5:1 for destroyers and cruisers, 10:1 to 12:1 for submarines, and 4:1 to 7:1 for aircraft carriers. Thus, the ability to differentiate between shapes that are relatively similar is useful in classifying the types of ships in a fleet or harbor, determining the types of vehicles at a base or along a road, and the classes of aircraft (e.g., interceptors, reconnaissance, light and heavy bombers) on an airstrip.

To obtain a better grasp of the effect of size on target recognition, Figure 4.2.1 illustrates the theoretical waveforms generated when a simple two-channel mask is used to scan a group of lines that vary in width over a wide range. As the target decreases in width from unity to zero the peak output reduces to zero at the same rate. Similarly, a linear relationship exists as the target is increased in width from unity to 150 percent of nominal mask width. As the target continues to increase in width beyond 150 percent, however, the output remains constant at 50 percent of maximum. A typical left-edge waveform is generated when the mask enters a large target and a typical right-edge waveform is produced when the mask leaves the right side of the target.

The heavy black line in Figure 4.22 consolidates this information and indicates that with a threshold set at 0.6 potential selectivity between targets that are similar in shape but vary in width may be achieved over the range of 60 percent of nominal mask size to 140 percent of nominal or a size range of 2.3 to 1. For the region beyond 150 percent the mask simply detects areas that are darker than their background rather than detecting specific shapes.



(Experimental Results)

Figure 4.20 - 5:1 Line Mask Output for Five Target Classes

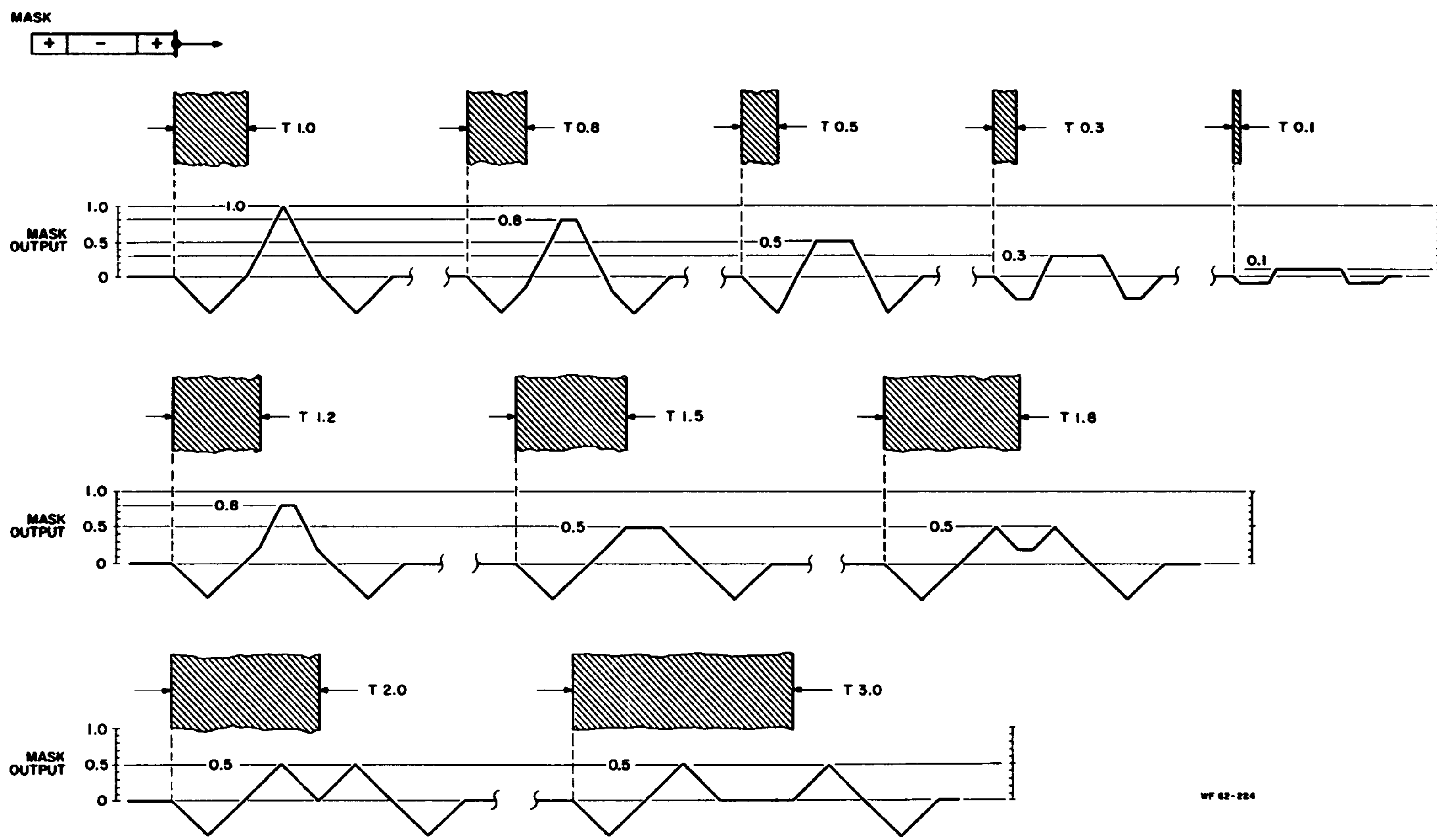


FIGURE 4.21. Mask Waveforms vs. Target Size

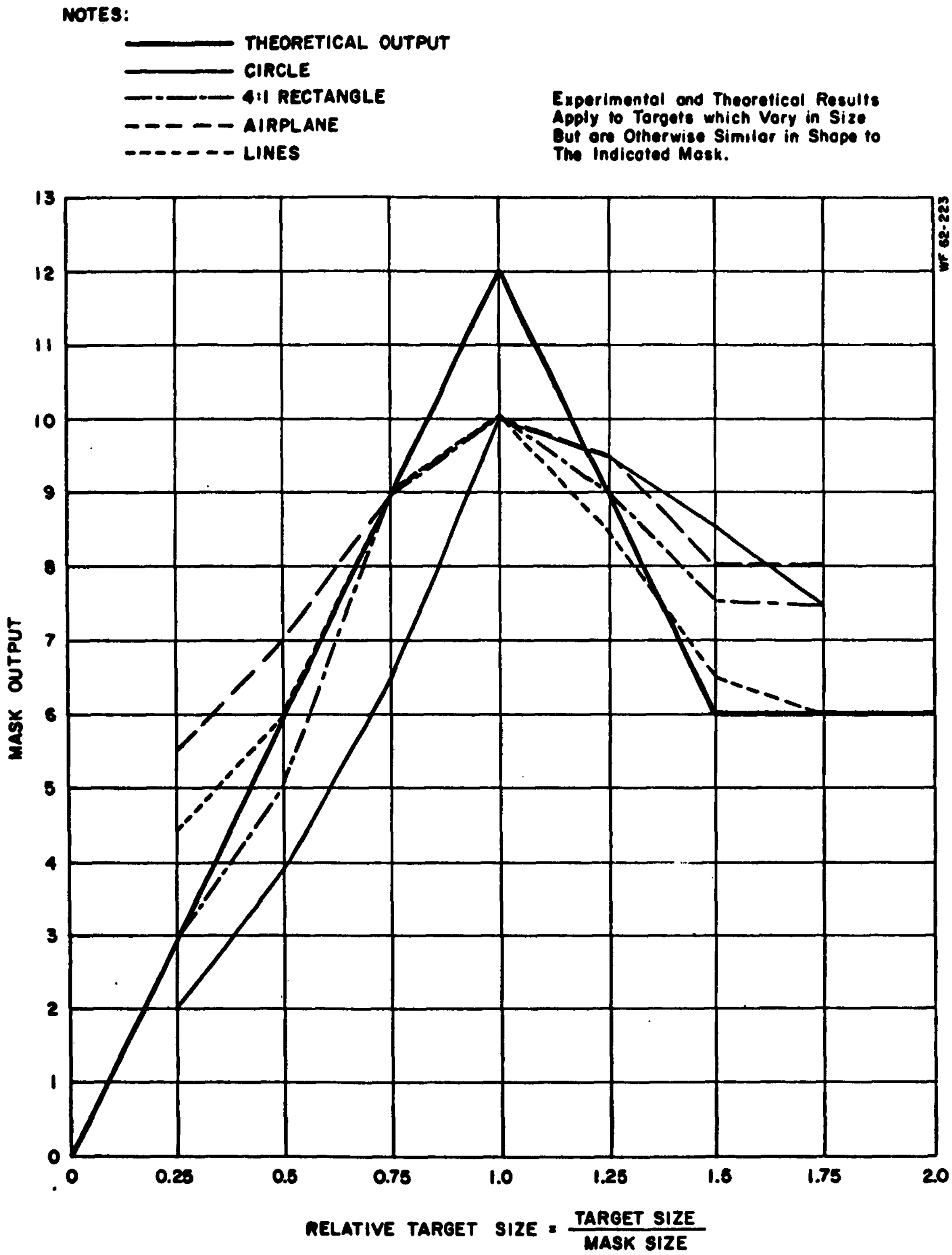


FIGURE 4.22. Mask Output vs. Target Size

Plotted in this same figure are the experimental output curves for four different masks when each scans targets that are similar to itself in shape but not in size. In no instance is the peak output at unity target size equal to twice the output obtained at 1 1/2 times unity target size, as had been predicted by the theoretical data. Due to the large spot size, the resolution in the SATRD scanner is not adequate to retain the sharp peak of the waveform displayed in Figure 4.21 for targets of unity target size, with the result that the maximum experimental mask output is approximately 15 % below the theoretical maximum.

4.3.3 Comparative Area Matching

At the beginning of this section the effect of varying contrast on target recognition was described. No definitive method was presented to differentiate between peak values obtained due to exact match in shape and size in a low contrast region versus partial match in a high contrast region. However, if the target is scanned simultaneously with several different masks, the effects of varying contrast can largely be eliminated. Each mask is subjected to the same dynamic contrast range with the result that all mask outputs will be affected by the same multiplicative factor. Consequently, the relative magnitudes become more significant than the absolute magnitudes.

This technique of performing target recognition by comparing the outputs of several different masks that are simultaneously scanning the same area and of classifying a target according to the mask which produces the maximum output, if above some threshold value, we shall call "comparative area matching". To simulate this technique with the SATRD, we have sequentially recorded the output of several different masks when scanning a group of targets and then plotted the results on a single sheet of graph paper. This permits ready comparison of the mask outputs for each target and subsequent classification of the target according to the mask producing the maximum output. In addition, we are able to determine over what range of target sizes can a single mask perform effectively, and therefore, how many masks will be required to perform target recognition over any desired range of target sizes or ground scales.

Experimental results obtained with "comparative" area matching are presented in Figures 4.23 to 4.26. In Figure 4.23 a group of 7 different airplanes varying in size over a total range of 7:1 is scanned by 4 different masks. While previously, in Figure 4.17, the region of selectivity ranged from 70 percent to 137 percent, selection can now be achieved over a 3.5:1 range of target sizes, or 55 percent to 175 percent of the target size. In addition, the correct mask produces an output at least 25 percent (and often 100 percent) greater than that developed by any other mask.

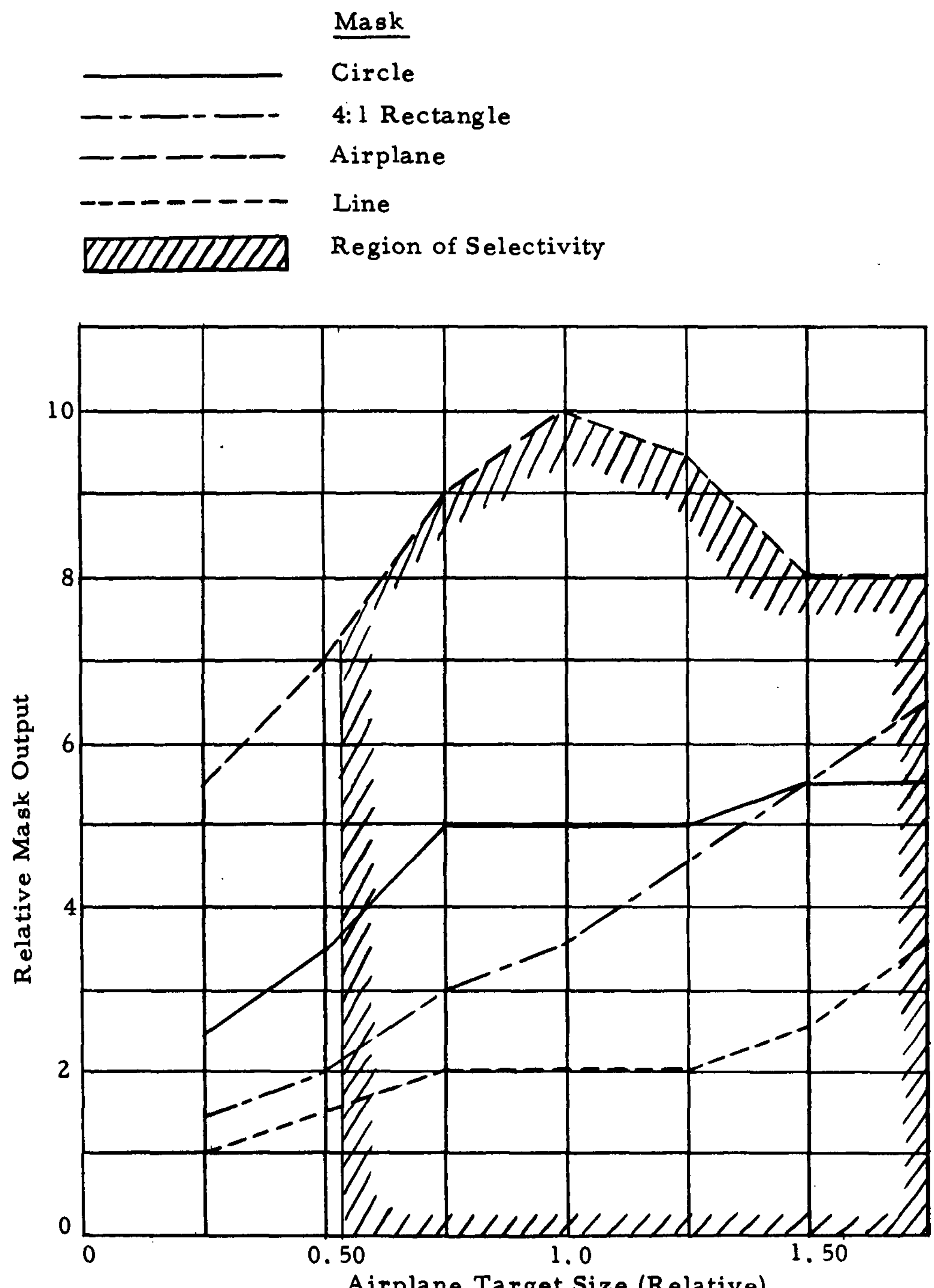


Figure 4.23 - (Experimental Results)
Comparative Area-Matching - Target: Airplanes

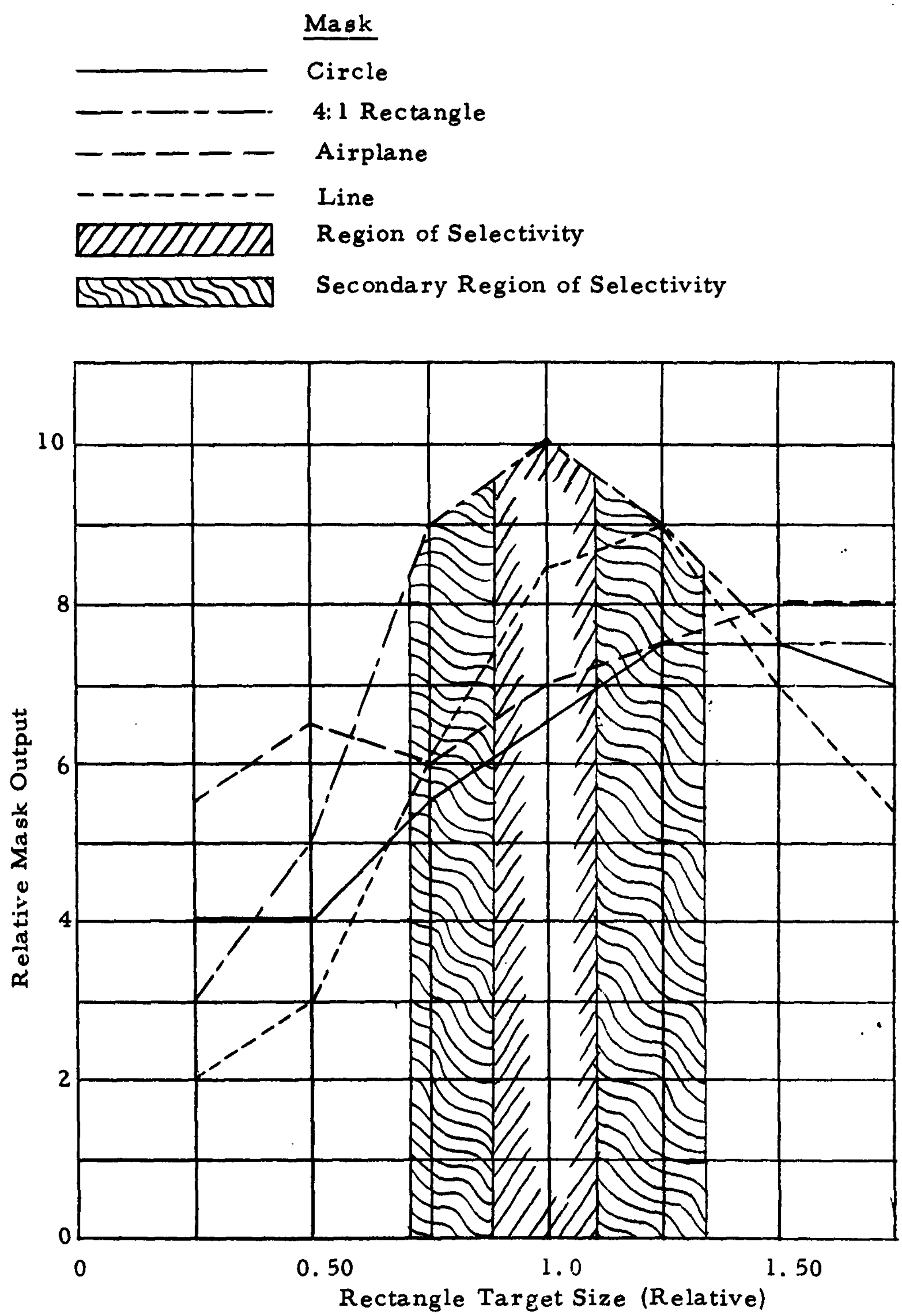


Figure 4.24 - (Experimental Results)
Comparative Area-Matching - Target:
4:1 Rectangles

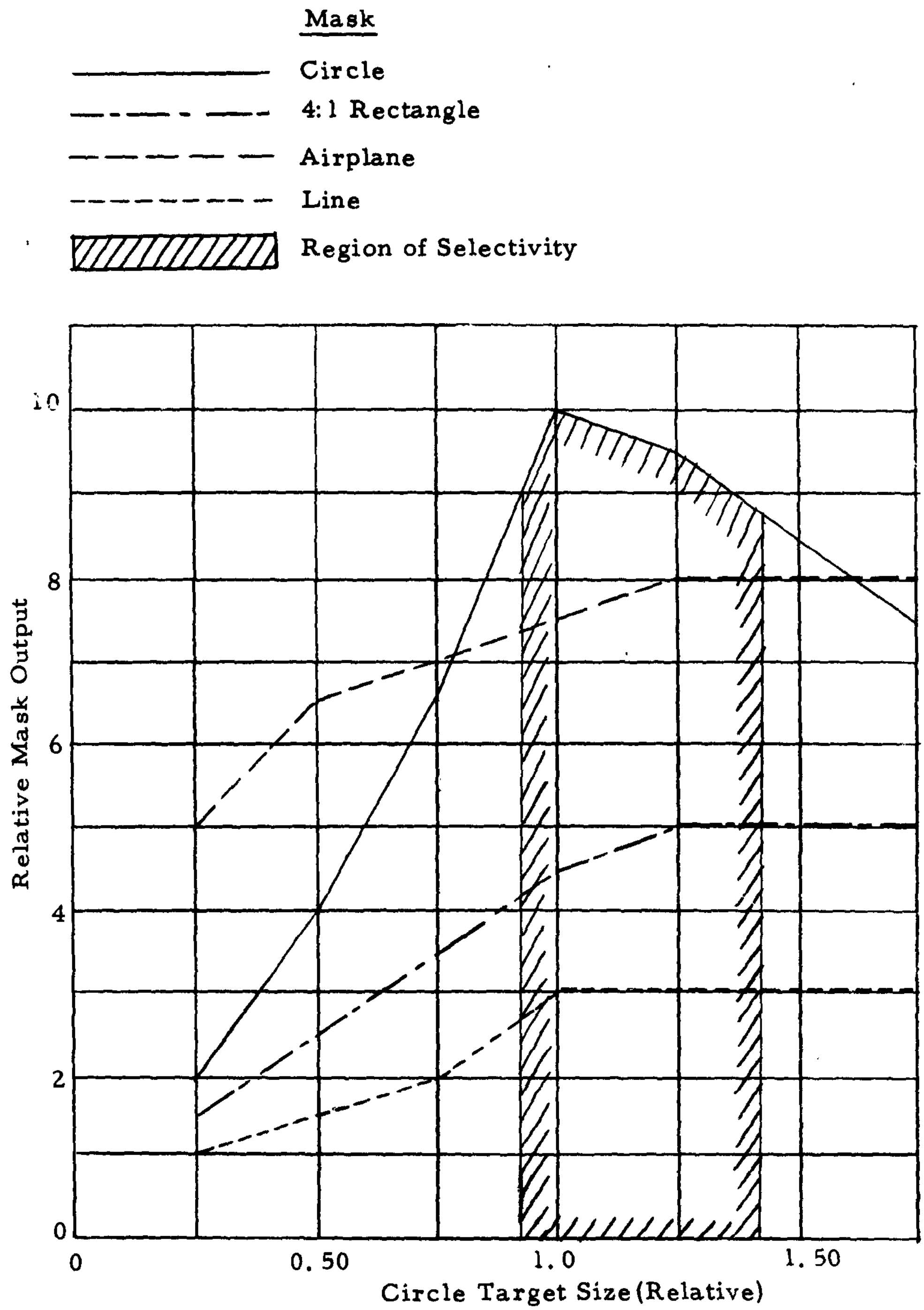


Figure 4.25 - (Experimental Results)
Comparative Area-Matching - Target: Circles

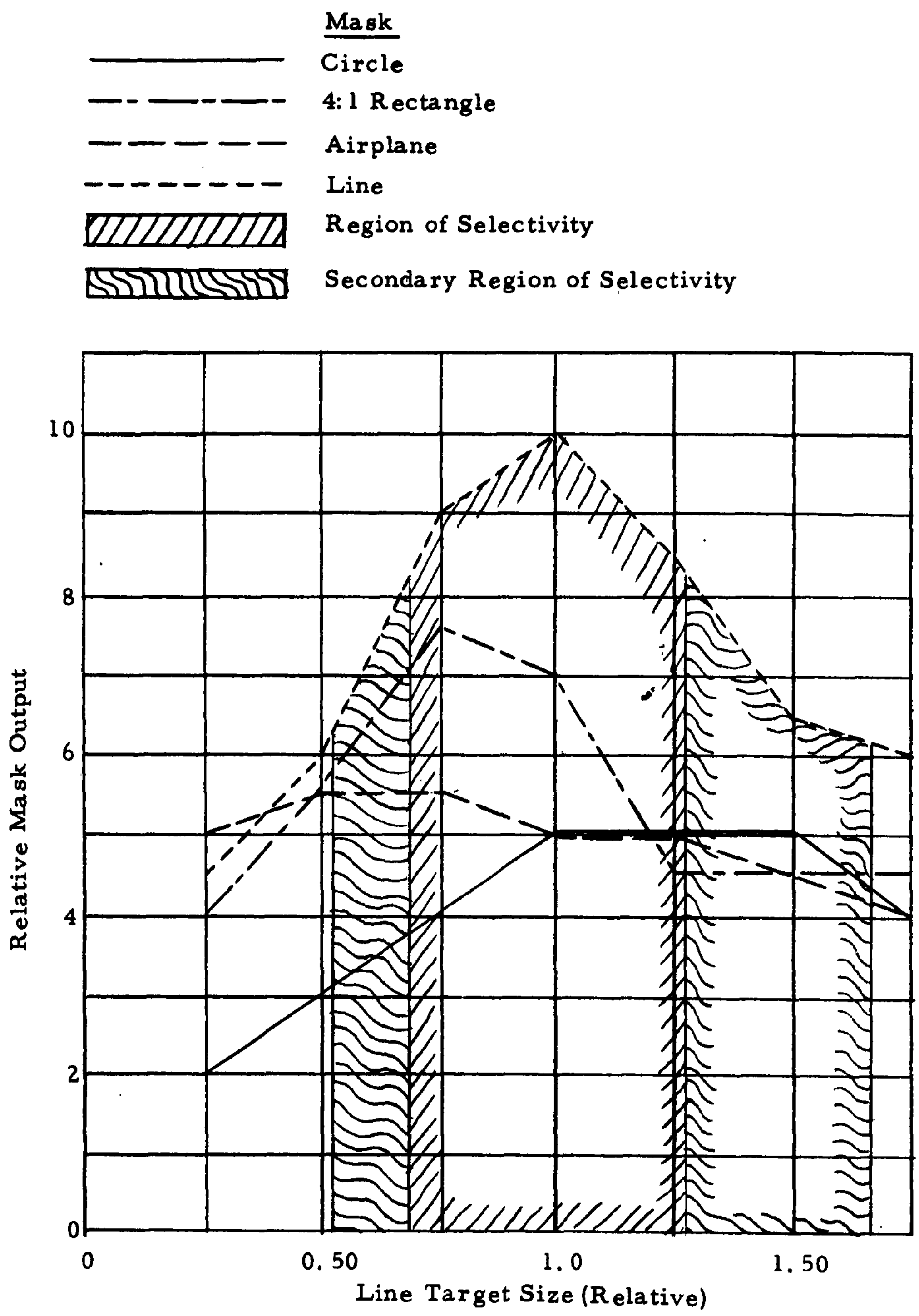


Figure 4.26 - (Experimental Results)
Comparative Area-Matching -
Target Lines

When the masks scan a group of 7 rectangles of 4:1 ratio, the change in the "region of selectivity" is not dramatic. This is apparent when comparing 4.24 and 4.18. Again the conflict between the relatively similar 4:1 rectangle mask and the 5:1 line mask severely limits the region of selectivity.

In Figures 4.25 and 4.26 similar results are plotted for circle targets and for line targets. The line mask in Figure 4.26 displays reliable recognition over a very wide range if the 4:1 rectangle mask is excluded from the comparison.

If the contrast of the targets illustrated in Figure 4.16 decreases, the curves of Figures 4.23 to 4.26 will uniformly shrink in amplitude but the relative magnitudes will remain unchanged. If the contrast of a single target decreases, the output for each mask scanning that target again decreases proportionally. As a result, with comparative area-matching the ability to make correct decisions is not affected by variations in dynamic contrast even along a single scan line.

4.3.4 Comparative Area Matching In Noise

The ability of comparative area matching to perform successful target recognition even in difficult surroundings is illustrated in Figure 4.27. In this figure a rectangle mask and a circle mask each scan a section of an aerial photograph which displays similar size targets in a region of varying dynamic contrast and low signal-to-noise ratio.

Preliminary to performing area-matching it is necessary to balance the output for a given mask by equalizing the flying spot scanner in-focus video output from each channel. This is illustrated in Figures 4.27a and 4.27b for the circle mask and in Figures 4.27e and 4.27f for the rectangle mask used in this example. When in-balance, the difference between the two-channel outputs is zero, as seen in Figures 4.27c and 4.27g; however, in 4.27g the excessive noise in each channel hides the balance condition, which exists at the output of the difference amplifier. After balancing, Lens L2 (Figure 5.1) is lowered, which brings the area mask into focus while defocussing the image of the scanner spot. The output of the difference amplifier (Figures 4.27d and 4.27h) now represents the area-match output, or the difference in output between the positive and negative portions of the two-channel mask.

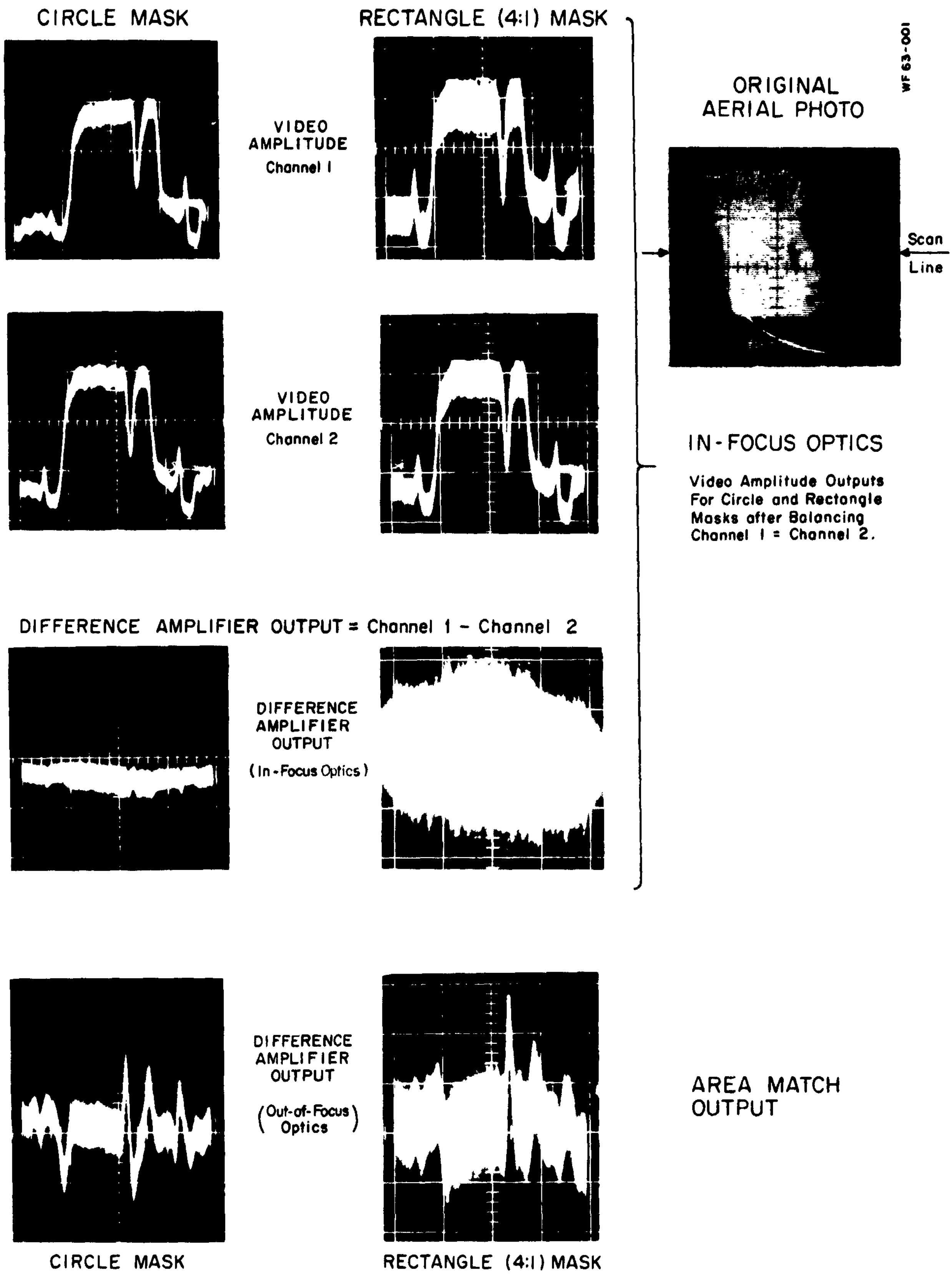


FIGURE 4.27. Comparative Area Matching in Presence of Noise

Both the circle and the rectangle mask display significant peaks above the noise level. When comparing the mask outputs, the peak in the output from the rectangle mask becomes dominant, thereby indicating the likelihood of an oil tanker in the river.

The remaining peaks cancel one another. The exceedingly low contrast and high density in the vicinity of the tank, the shadows and the close proximity of the shore-line all contribute to unsuccessful recognition of the oil tank. To better interpret the effect of "clutter" and spacing of adjacent targets on target recognition the next section presents a brief study of the effect of target spacing on recognition.

4.3.5 Effect of Variations In Target Spacing

Because of the width of the masks used in area matching, the waveforms generated are always wider than the targets across which they are scanned. With the result that close proximity between targets modifies the output waveforms and generally reduces the ability of a mask to perform successfully. In this section, the results of a brief study made to evaluate the effect of close target spacing on target recognition are presented.

The waveforms that are generated when a conventional two-channel mask scans targets which match the mask exactly but which have varied spacing between targets is presented in Figure 4.28. As long as the targets are more than two target widths apart, the output waveforms are unaffected by the spacing. As the targets are brought to within one-half the target width of one another, only the positive peaks remain unaffected. If the target spacing is gradually decreased to zero, the positive output decreases linearly to 0.5, at which time the mask can no longer differentiate between the two individual targets and a new target of twice the width of the desired target. These results are summarized in Figure 4.29.

Up to this time the waveforms presented in this chapter have referred to dark targets against a light background; however, light targets against a dark background will produce waveforms that are identical but inverted to those previously displayed. The significance of the increase in negative output for values of target spacing between 0.5 and 1.5 can now be readily understood. To the mask, the light area between the dark targets simply looks like a light target against a dark background, with the result that an absolute output fully as large as that for dark targets is obtained when the mask width equals the target spacing. For successful area-matching it is necessary to examine

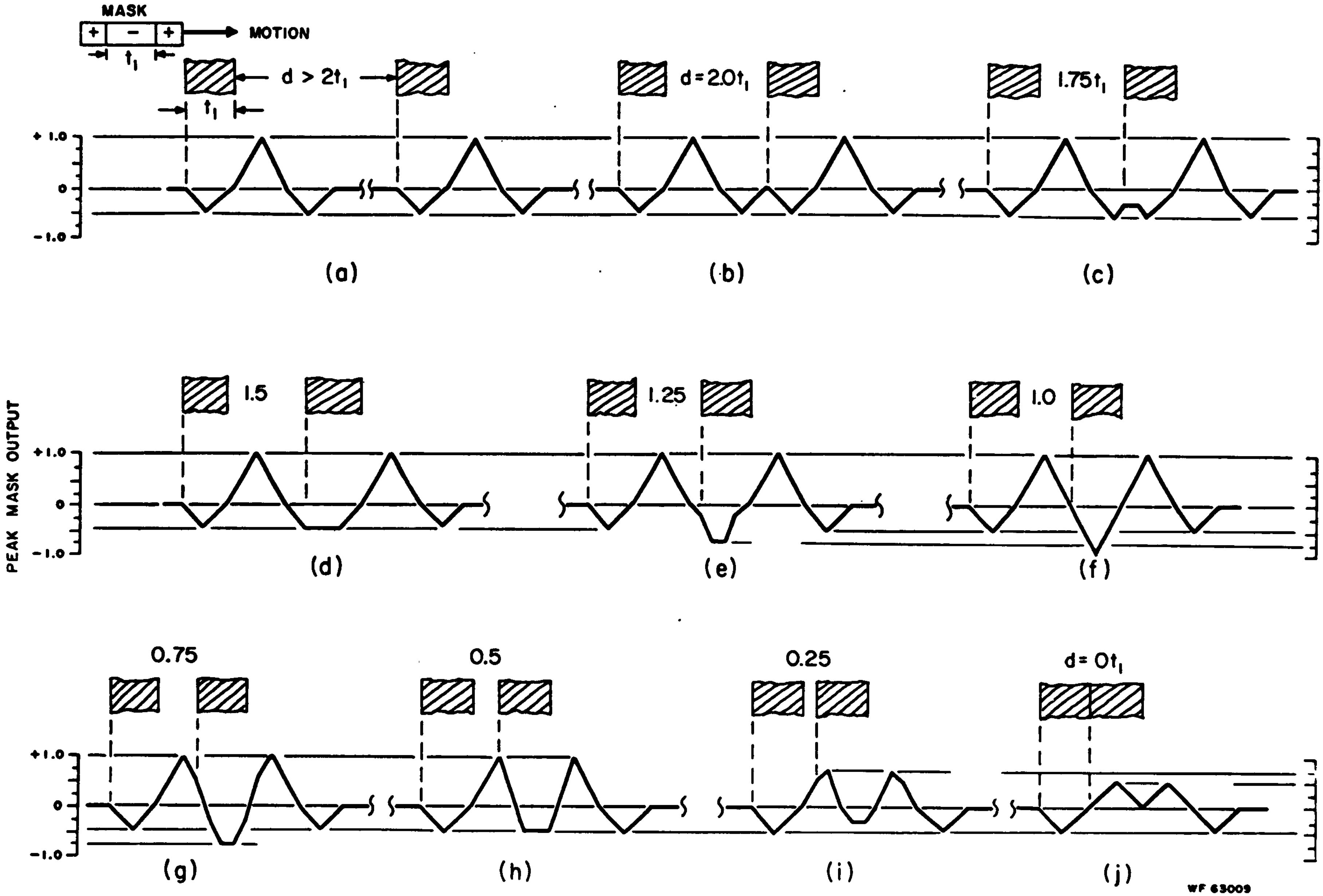


FIGURE 4.28. Mask Waveforms vs. Target Spacing

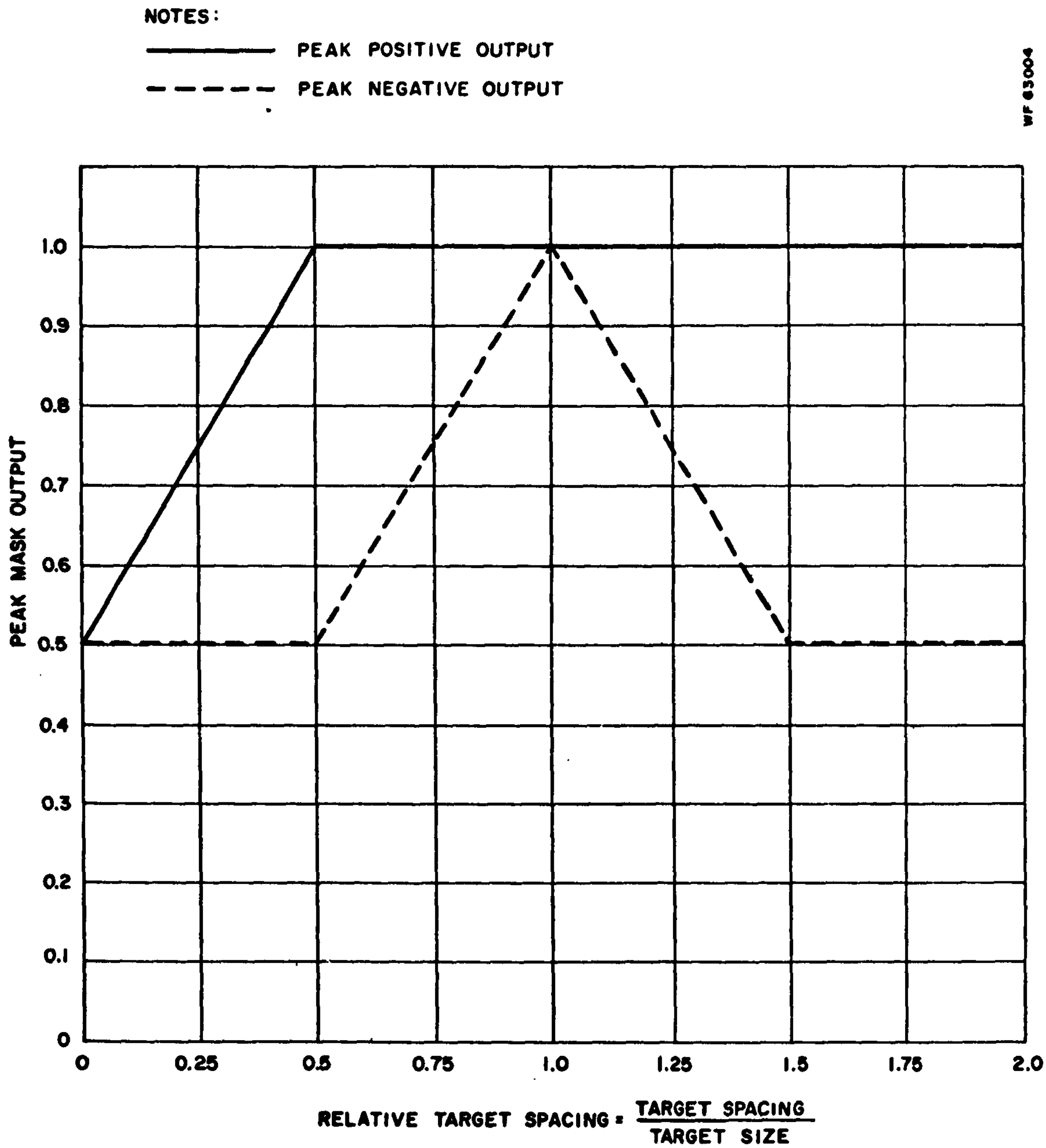


FIGURE 4.29. Mask Output vs. Target Spacing

both the positive and the negative peaks of the mask output waveform, which can readily be accomplished by rectifying the waveform and counting all peaks above a threshold of 0.5.

For masks of complex shape there is no single target width that can be referred to in analyzing the effect of target spacing. For example, the airplane mask of Figure 4.14 may be considered as the sum of two crossed rectangular masks. The output waveforms would be a composite of that produced by each rectangle, and the effect of the close proximity between airplanes will be different for the fuselage rectangle than for the wing rectangle. Since the actual shape of the airplane mask is somewhat more complex than merely two crossed rectangles, the actual affect of target spacing is difficult to determine on a theoretical basis. Airplanes on a runway or apron may be close together and yet the orientation of the planes may vary widely. This adds complication to the theoretical results reported here and indicates that an experimental study is necessary to fully clarify the effect of target spacing on target recognition.

In this section we have seen that a single-channel mask is readily deceived by any large dark region, while the two-channel mask system successfully solves this problem. We have also seen that area matching, in general, is affected by variations in dynamic contrast, while "comparative area matching" successfully resolves this difficulty.

V. DESCRIPTION OF THE SATRD

This section describes the Semiautomatic Target Recognition Device (SATRD), which was developed to verify the feasibility of applying pattern recognition and identification techniques to the problem of aerial reconnaissance photo interpretation.

The initial study phase of this program indicated that both electrical and optical measurements may be employed to establish suitable categorization parameters. In order to retain maximum flexibility and to permit the comparison of these two techniques, the SATRD has been constructed to permit the extraction of both types of parameters.

The SATRD (Figure 5.1) consists of a flying spot scanner and photomultiplier transducer to convert the pictorial input information (selected frames of aerial photography) into a video signal, on which various measurements are made to determine the parameter values for a specific region of the photograph. The flying spot scanner may be operated in a conventional manner with a small circular spot for electrical measurements. Alternatively, the scanning spot may be shaped by a mask and optical system to permit the extraction of electro-optical parameter measurements. Although the equipment is capable of handling a 500 foot roll of nine inch film, the area illuminated by the flying spot scanner is restricted to a specific one inch square area on the selected frame under examination. The one inch square is sufficiently large to encompass any of the target areas under consideration, using aerial photography taken at scales from 18,000:1 to 30,000:1. The entire frame may be examined by sequentially indexing the selected frame over the one inch scanned area.

The basic system block diagram is shown in Figure 5.2. The SATRD may be operated in a number of modes, which are selectable by the operator. The extraction of parameters from photographs is performed by automatic equipment which does not require a qualitative evaluation of the photographs by the operator. The parameters which are automatically extracted vary widely in physical interpretation, but they fall into two major categories:

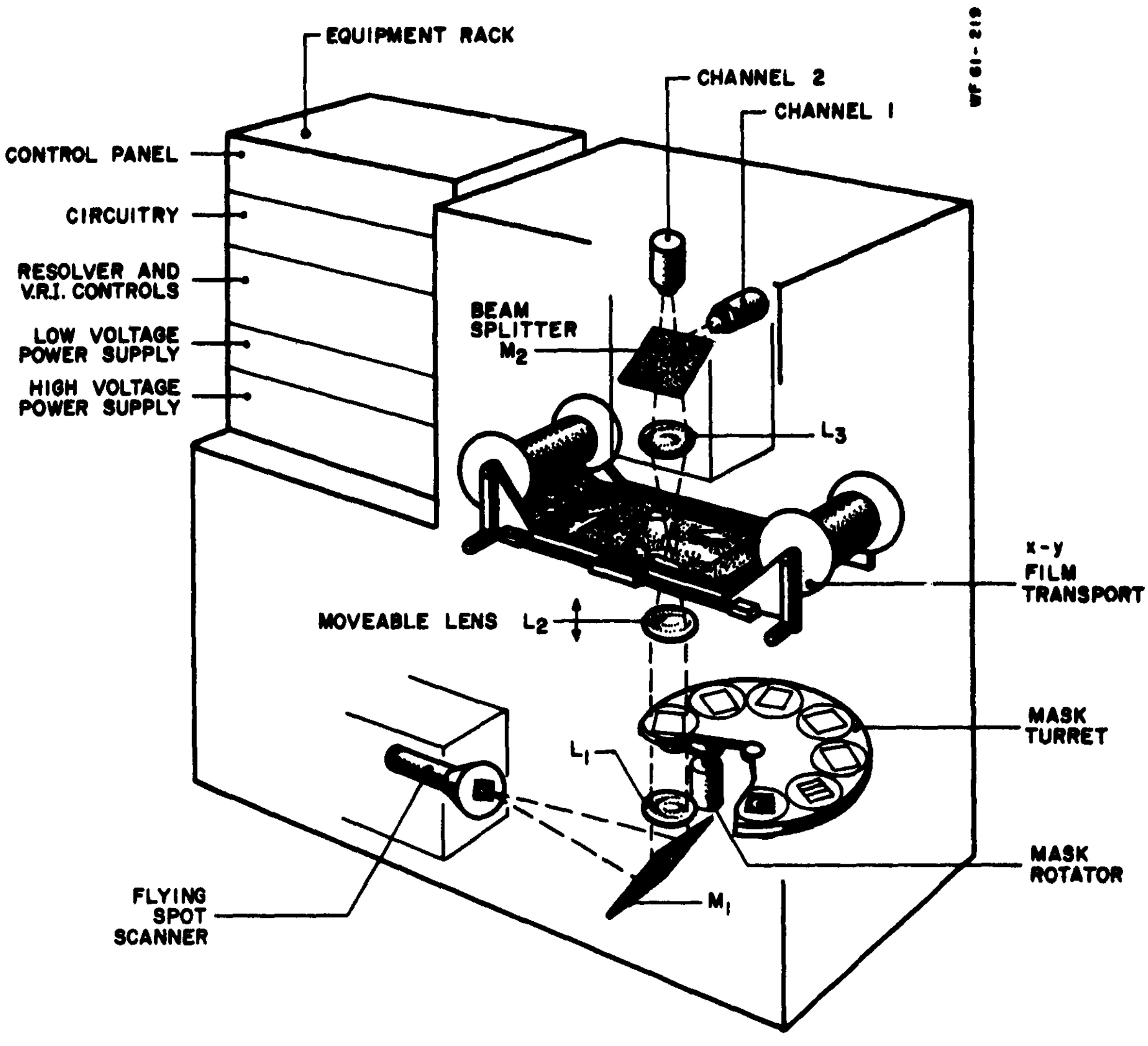
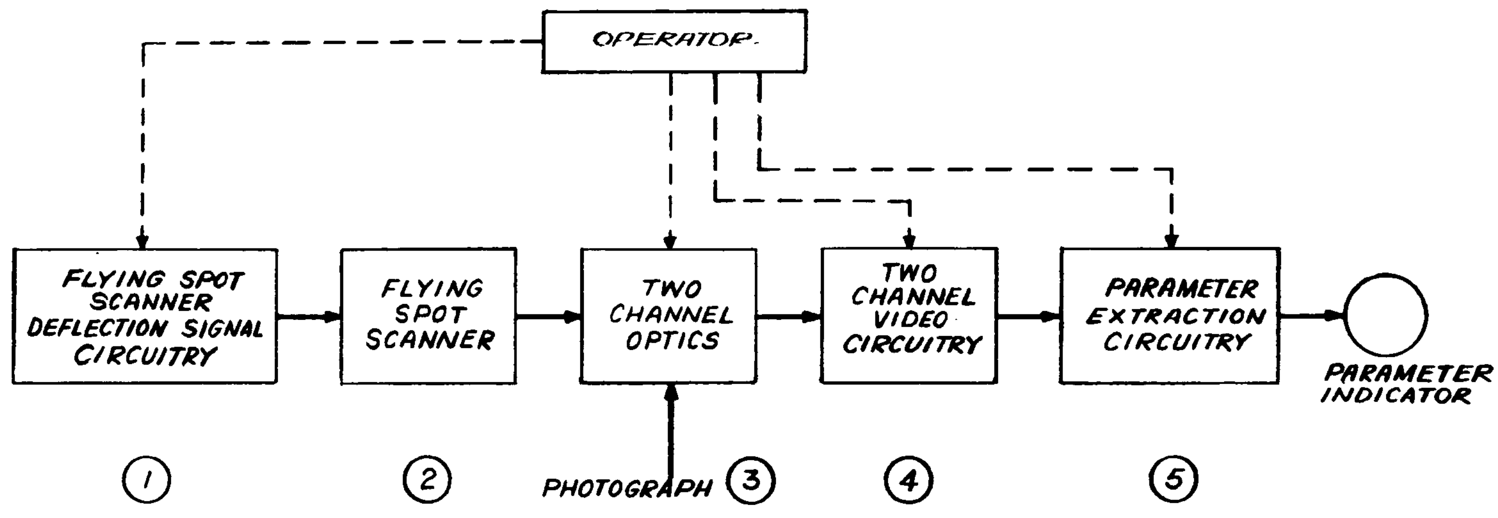


Figure 5. 1 Semi-Automatic Target Recognition Device (SATRD)



NOTE: DOTTED LINES INDICATE FUNCTIONS PERFORMED BY HUMAN ACCORDING TO INSTRUCTION LIST.

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Figure 5.2 System Block Diagram

a) Electrical parameters - these are measured by circuitry which operates on the video signal generated by a flying spot scanner illuminating an aerial photograph. The basic system resolution capability is, as in conventional flying spot scanners, determined primarily by the CRT spot size.

b) Optical parameters - these are measured by circuitry operating on the difference output of two photomultipliers in a two channel optical system (separation of channels is achieved by use of color filters). The negative is scanned by a two-color mask image shaped to represent objects of interest. The size of the mask image which is scanned over the negative may be adjusted by varying the image distance in the optical system.

As a photographic transparency is scanned, the electrical output from a photomultiplier which collects the transmitted light provides a measure of the transmissivity of the transparency as a function of time, along the path scanned by the spot. If a region of the transparency were scanned in a uniform pattern, the integral of the photomultiplier output serves as a measure of the average transmissivity in that region, while the derivative of the photomultiplier output signal is used for specific object boundary detection.

The detection of boundary crossings is accomplished by differentiating the video output signal, and it is important that scanner writing speed be kept constant since a change in scan speed varies the amplitude of the derivative spike derived from the boundaries. By setting an amplitude threshold on the derivative, gradual changes of transmissivity from one part of a photograph to another are prevented from giving false boundary indications. Since photographic transparencies are not composed of ideal opaque and transparent areas, the system must operate with changes in gray level as a negative is traversed by the scanning spot. Thus the setting of an amplitude threshold on the derivative which denotes a boundary crossing is equivalent to defining a boundary in terms of a minimum change in gray level on the negative, within the diameter of the scanning spot.

A wide variety of electrical parameters may be extracted from negatives by combining properties of detected boundary crossings and scanning patterns. For example, consider the measurement of frequency of occurrence of boundary crossings when a television scan is used. For any one direction of the scan, the frequency of occurrence of boundaries is approximately a measure of the number of edges which are perpendicular to the TV-scan direction. The change in frequency of occurrence of boundaries as the scan pattern is rotated is therefore a measure of the degree to which preferred directions of edges occur in the region being scanned.

A detailed description of the electronic circuitry, the optical system, and the hardware is included in Appendix I .

VI. TEST DATA USED IN THE PROGRAM

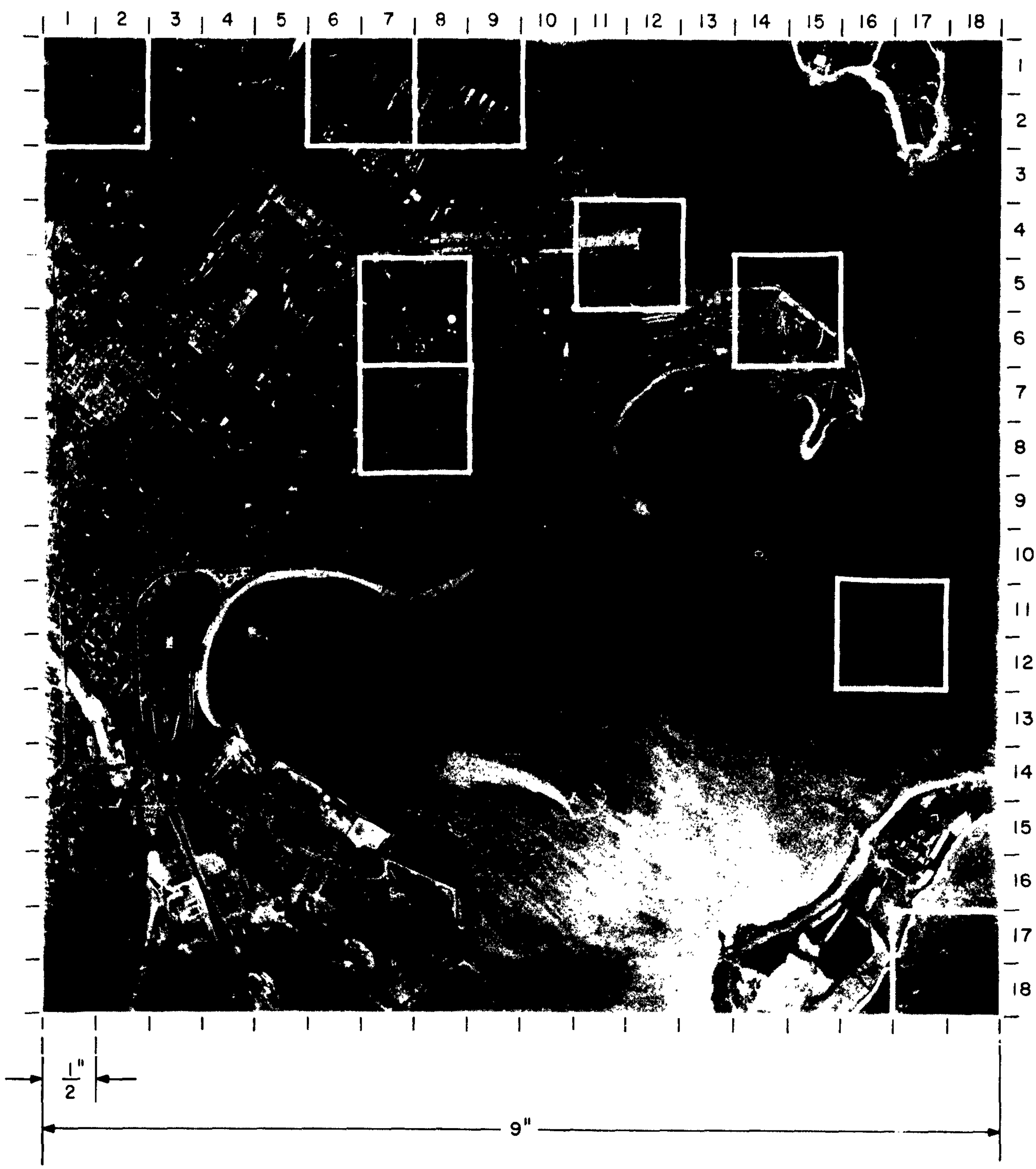
A set of 101 frames of 9 inch by 9 inch vertical incidence aerial photographs was selected from rolls of negative film supplied by the contracting agency. Frames were selected on the basis of displaying a typical range of samples of each target class from which parameters could be extracted and subsequent computer aided machine learning and recognition be performed. To limit this program to one of proving feasibility of concepts rather than to develop a piece of finished field-type hardware capable of handling a wide range of scale factors, a scale range of 1:18,000 to 1:30,000 was chosen.

After consultation with RADC the following group of target classes was selected to be of significant strategic interest, as well as useful in the development of the Semiautomatic Target Recognition Device.

Class No.	Symbol	Description
1	I	Industrial Area
2	U	Urban Area
3	H	Harbor
4	A	Airfield
5	R	Railroad
6	B	Bridge
7	T	Tank Farm
8	O	Ocean
9	F	Flatland
10	W	Woodland

Halftone positives of typical sample films are displayed in Figures 6.1, 6.2 and 6.3. Several one-inch sample squares have been outlined to illustrate the average size and appearance of the neighborhoods used to represent single targets.

Data has been collected and preliminary analysis has been made on a subset consisting of 15 samples of each of the 10 classes. For this particular subset totalling 150 samples, the following eleven parameters have been extracted:



SCALE : 1" = 1650 feet

(ROLL 1 , FRAME 3 , ALTITUDE 9,900 ft)

Figure 6.1 Typical Aerial Film: Urban, Harbor

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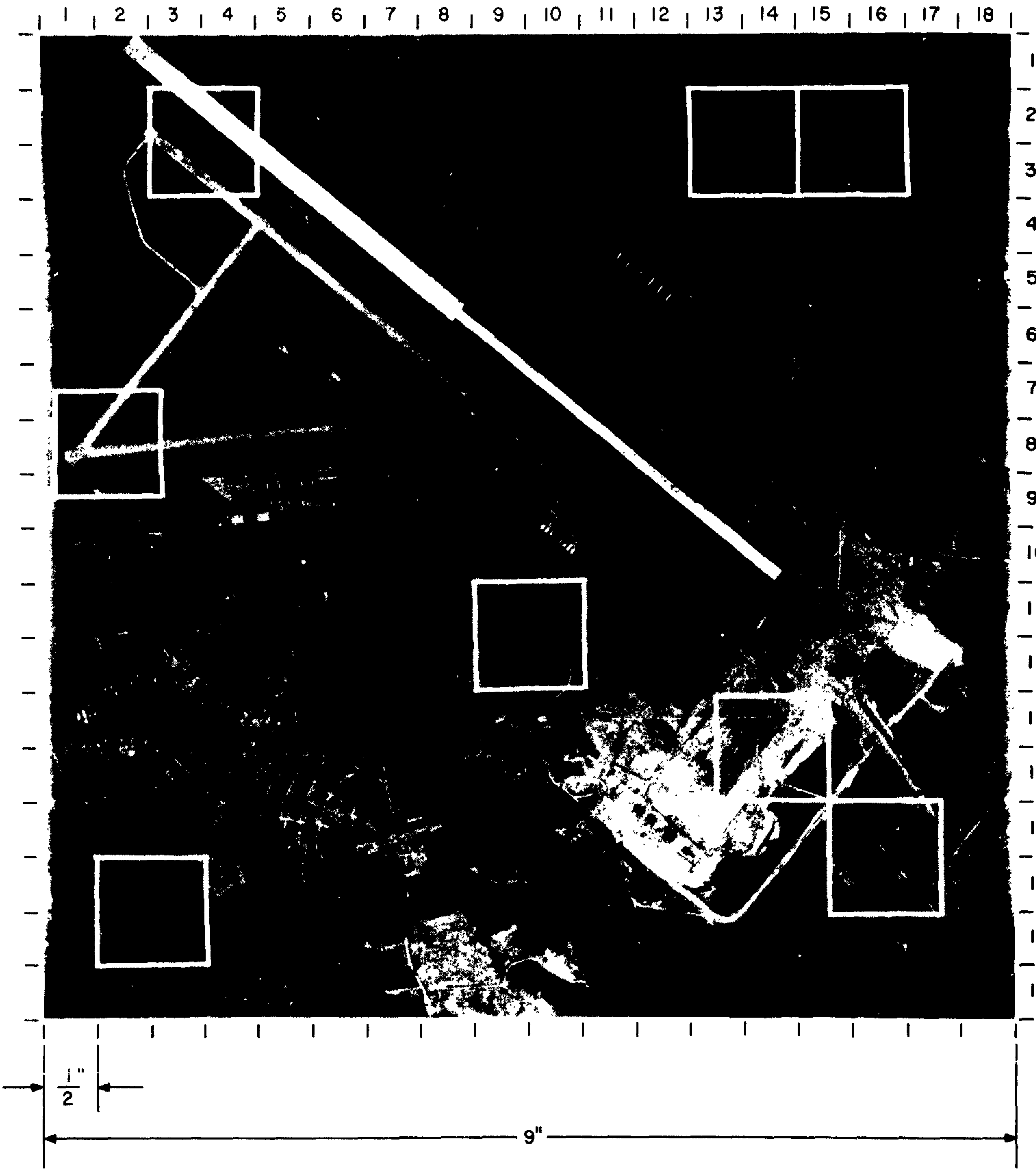
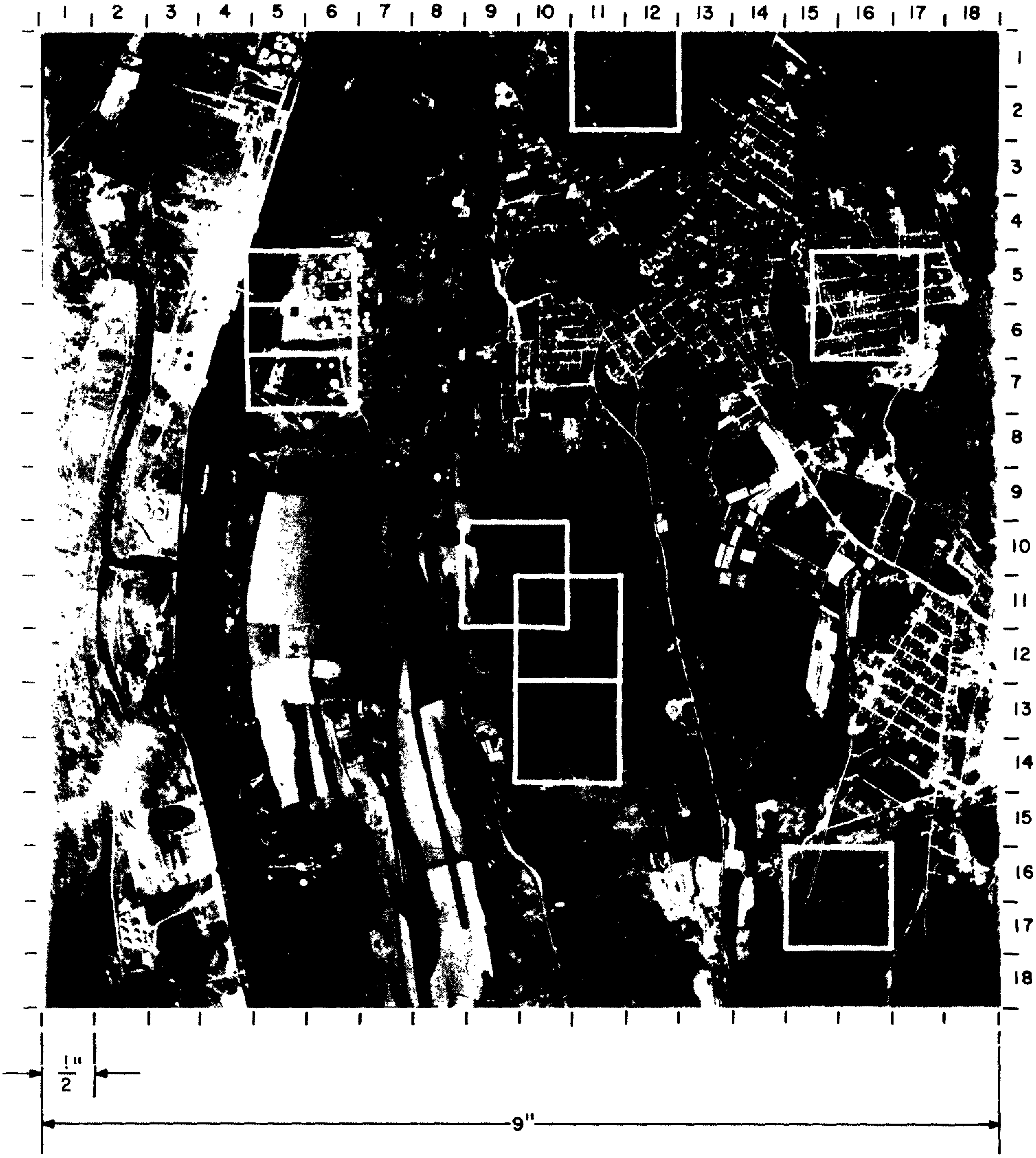


SCALE: 1" = 1600 feet

(ROLL 6, FRAME 111, ALTITUDE 9,500 ft.)

Figure 6.2 Typical Aerial Film: Airfield, Industrial



SCALE : 1" = 1650 feet

(ROLL 1, FRAME 138, ALTITUDE 9,900 ft)

Figure 6.3 Typical Aerial Film: Tank Farm, Woodland

P_1 = Photographic detail per unit area (using an isotropic scan). This parameter is expected to distinguish urban areas and other target types that have high density of objects from those that have a relatively low density of object detail.

P_2 = Ratio of highest to lowest value of photographic detail (using a rotating TV scan).
This parameter is expected to measure the average length to width ratio of object detail encountered on the picture. Urban areas are expected to have a nearly unity value of P_2 while certain industrial complexes are expected to have a large value of P_2.

P_3 = Ratio of highest to lowest value of uniformity of boundary crossing intervals for rotating TV scan (to measure the average shape factor of objects).
This parameter is by no means identical to P_2 as was determined by experiment.

P_4 = Highest value of photographic detail (employing a rotating TV scan).

P_5 = Highest value of uniformity of boundary crossing intervals, for a rotating TV scan.

P_6 = Number of times the uniformity of boundary crossing interval output exceeds 90 percent of the maximum value, for a rotating TV scan (to measure number of preferred directions for line spacing).

P_7 = Width of narrowest peak in the uniformity of boundary crossing output, where a peak is defined as being about 90 percent of maximum value (to measure sharpness of rotational preference).

P_8 = Same as P_6, for photographic detail rather than uniformity of boundary crossings.

P_9 = Same as P_7, for photo detail rather than uniformity of boundary crossings.

P_{10} = Same as P_6, with a 70 percent threshold instead of 90 percent (to measure number of very <u>strong</u> directional peaks, as opposed to P_6 which uses a weaker peak detection criterion).

P_{11} = Same as P_7, with a 70 percent threshold rather than 90 percent.

The data for each of the target classes has been recorded in tabular form, punched tape, tabulating cards and magnetic tape. Tables of numerical data extracted with the SATRD for two classes - Industrial Areas and Harbors - are illustrated in Figures 6.4 and 6.5.

It has frequently been found desirable while extracting numerical and graphical data from sample films to monitor the detection process with a laboratory oscilloscope set up adjacent to the SATRD, as illustrated in Figure A-15. Scan drive signals are sent both to the scanner and to the monitor scope, thereby generating at the monitor a duplicate of the TV, rotating TV, or isotropic raster being generated in the scanner tube. The video output signal, which is normally used as the input to the basic measurement circuits, is also used to intensity modulate the monitor scope thus producing a television-like image of the test cell. To increase the usefulness of the display, the output of the parameter extraction circuit in use is frequently superimposed on the video image to produce an enhanced image pictorially displaying the functioning of the circuit. An adjustable potentiometer permits varying the emphasis given to the video display as compared to the superimposed signal.

Several examples of cell images that have been monitored together with photographs illustrating the superposition of detail pulses on the video image are given in Figures 6.6 through 6.9. Comparison of the monitor image with the numerical values of the parameter being extracted has proven useful in explaining why certain targets of one class have proved difficult to separate from a group of targets of a different class.

Parameters employing the voltage range indicating circuit and the degree of area match equipment have not been extracted for the entire set of sample photographs. The system of area matching, however, was examined in some detail to evaluate its usefulness as a source of parameters in automatic target recognition. The results of this examination are reported in Section 4.3.

Class No. 1 - (I) INDUSTRIAL AREA

Run No. 2

Sample No.	Sequence No.	Subclass	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
1	1		13.	1.6	3.5	89.	14.	5.	1.	4.	1.75	4.	1.25
2	2		15.	1.7	3.3	96.	13.	4.	.06	4.	1.5	7.	.06
3	3		13.	1.1	1.5	80.	9.	2.	.75	0.	10.	0.	10.
12	4		15.	1.4	3.3	93.	13.	6.	..69	4.	2.	4.	1.0
13	5		13.	1.3	2.5	89.	10.	6.	.13	2.	2.44	4.	1.87
14	6		13.	1.1	2.0	73.	12.	1.	.06	0.	10.	14.	.06
15	7		10.	1.0	1.6	70.	11.	9.	.06	0.	10.	0.	10.
16	8		10.	1.2	1.6	84.	11.	2.	.13	4.	2.25	0.	10.
23	9		12.	1.2	2.4	80.	12.	2..	.56	5.	2.87	4.	1.75
24	10		14.	1.1	2.0	120.	6.	2.	.25	0.	10.	6.	.25
25	11		11.	1.1	1.5	87.	9.	4.	.13	0.	10.	14.	.06
26	12		13.	1.1	1.4	81.	7.	2.	1.3	0.	10.	2.	9.5
27	13		14.	1.1	2.0	78.	8.	16.	.06	2.	9.	0.	10.
28	14		19.	1.2	1.8	98.	7.	0.	0.	0.	10.	0.	10.
29	15		20.	1.1	1.5	105.	6.	4.	.06	0.	10.	2.	9.25

Figure 6.4 Raw Parameter Data for: Class No. 1

Class No. 2 - (U) URBAN AREA

Run No. 2

Sample No.	Sequence No.	Subclass	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
6	1		14.	1.1	1.6	80.	8.	4.	.25	2.	.5	3.	2.75
7	2		15.	1.2	2.	85.	10.	2.	.13	4.	1.	8.	.06
11	3		33.	1.1	2.	158.	4.	1.	.06	0.	10.	6.	.06
12	4		35.	1.1	2.	148.	4.	2.	.13	0.	10.	6.	.06
13	5		25.	1.2	1.7	124.	5.	2.	.56	2.	.5	0.	10.
22	6		15.	1.2	1.8	93.	9.	4.	.25	4.	1.75	4.	2.25
23	7		21.	1.1	2.	101.	6.	2.	.13	0.	10.	6.	.06
25	8		25.	1.2	1.3	134.	4.	2.	1.	0.	10.	4.	2.5
26	9		26.	1.2	1.7	130.	5.	4.	.44	0.	10.	4.	1.63
28	10		29.	1.1	1.7	126.	5.	4.	.75	0.	10.	5.	2.
29	11		36.	1.	1.3	158.	4.	0.	0.	0.	10.	0.	10.
30	12		27.	1.1	1.7	135.	5.	1.	.13	0.	10.	6.	.5
31	13		35.	1.1	2.	163.	4.	0.	0.	0.	10.	6.	.5
32	14		35.	1.	1.3	158.	4.	0.	0.	0.	10.	0.	10.
33	15		27.	1.0	2.5	131.	5.	8.	.69	4.	.5	4.	1.75

Figure 6.5 Raw Parameter Data for: Class No. 2

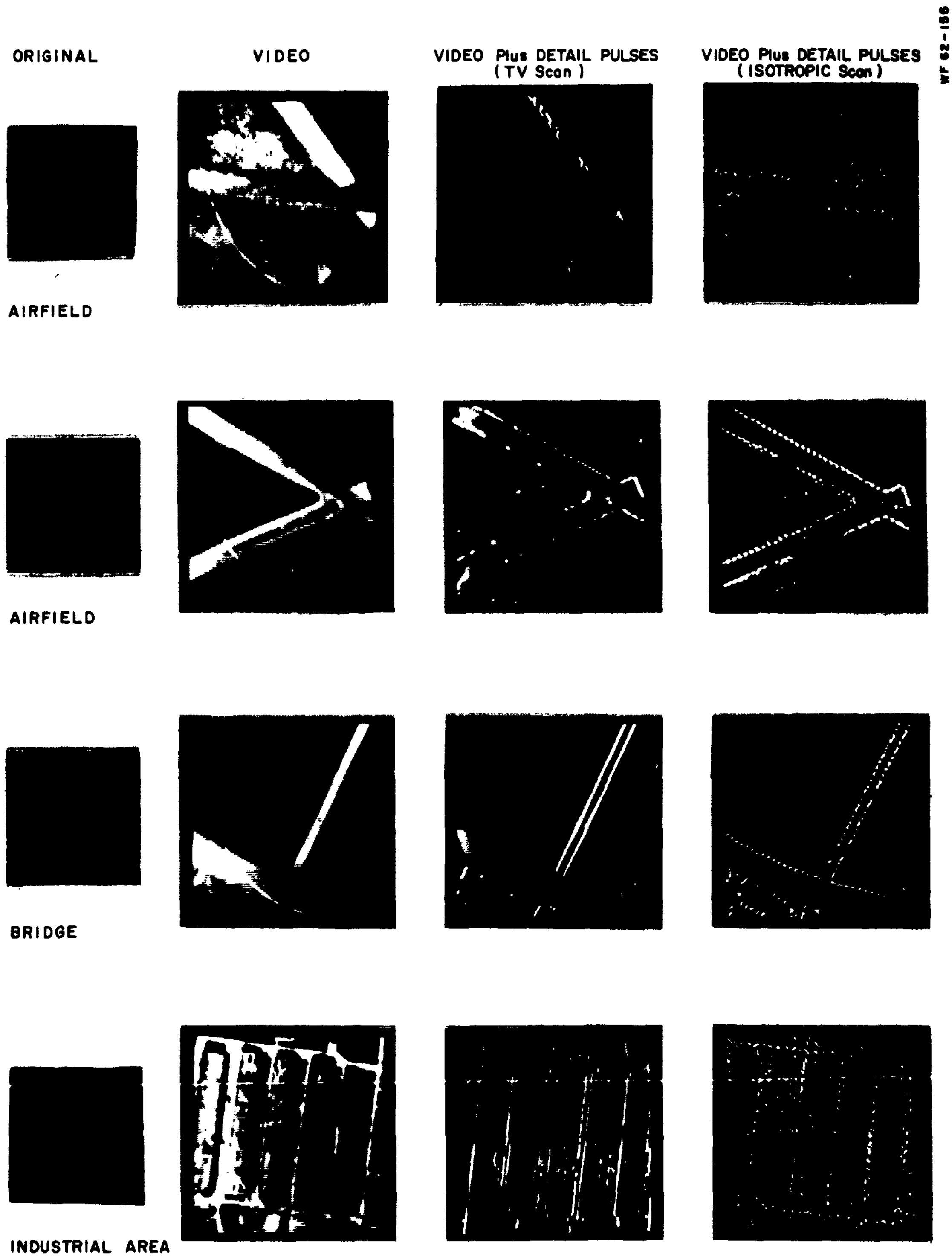


Figure 6.6 Representative Video Samples: Group I - TV and Isotropic Scans

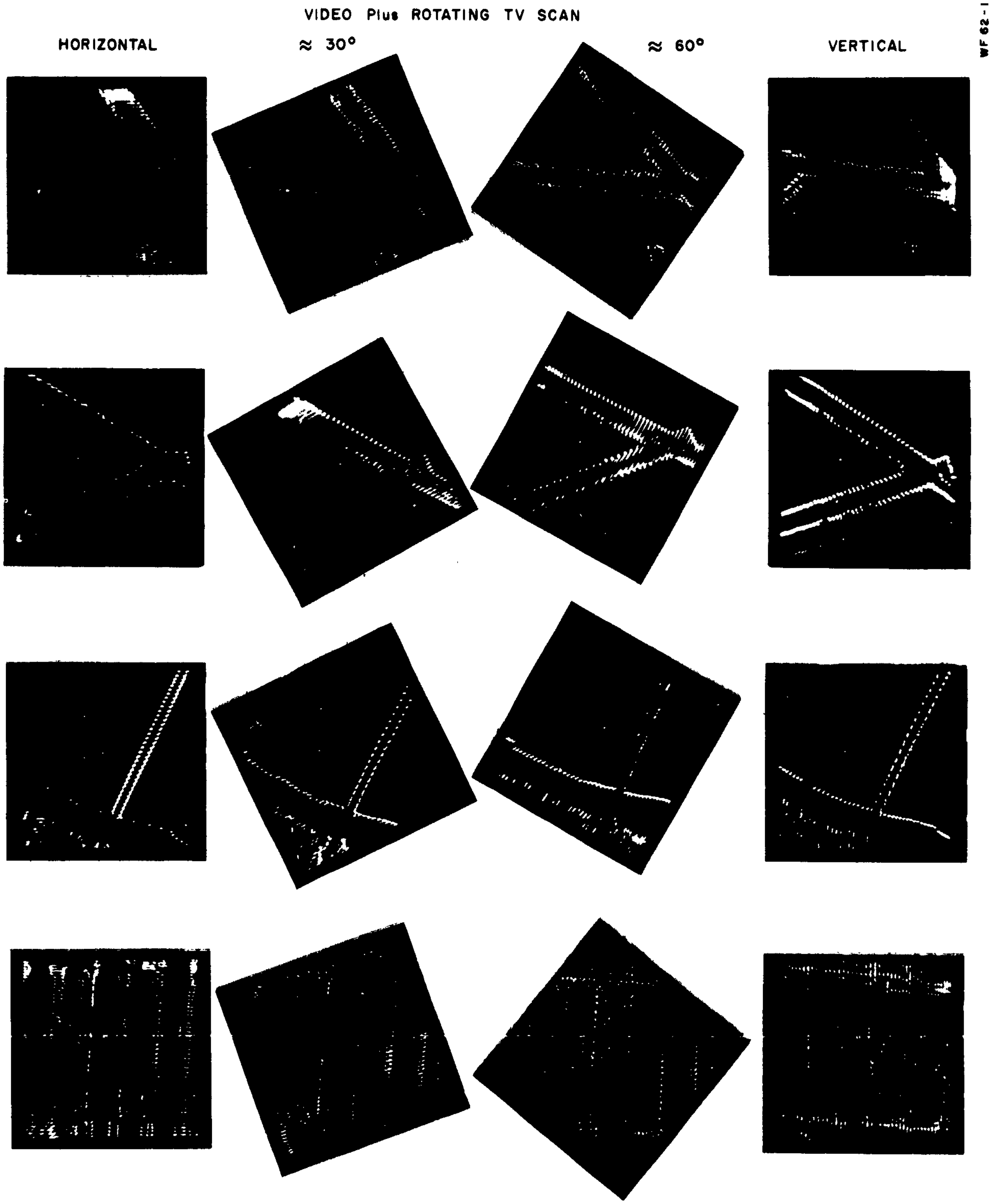


Figure 6.7 Representative Video Samples: Group I - Rotating - TV Scan

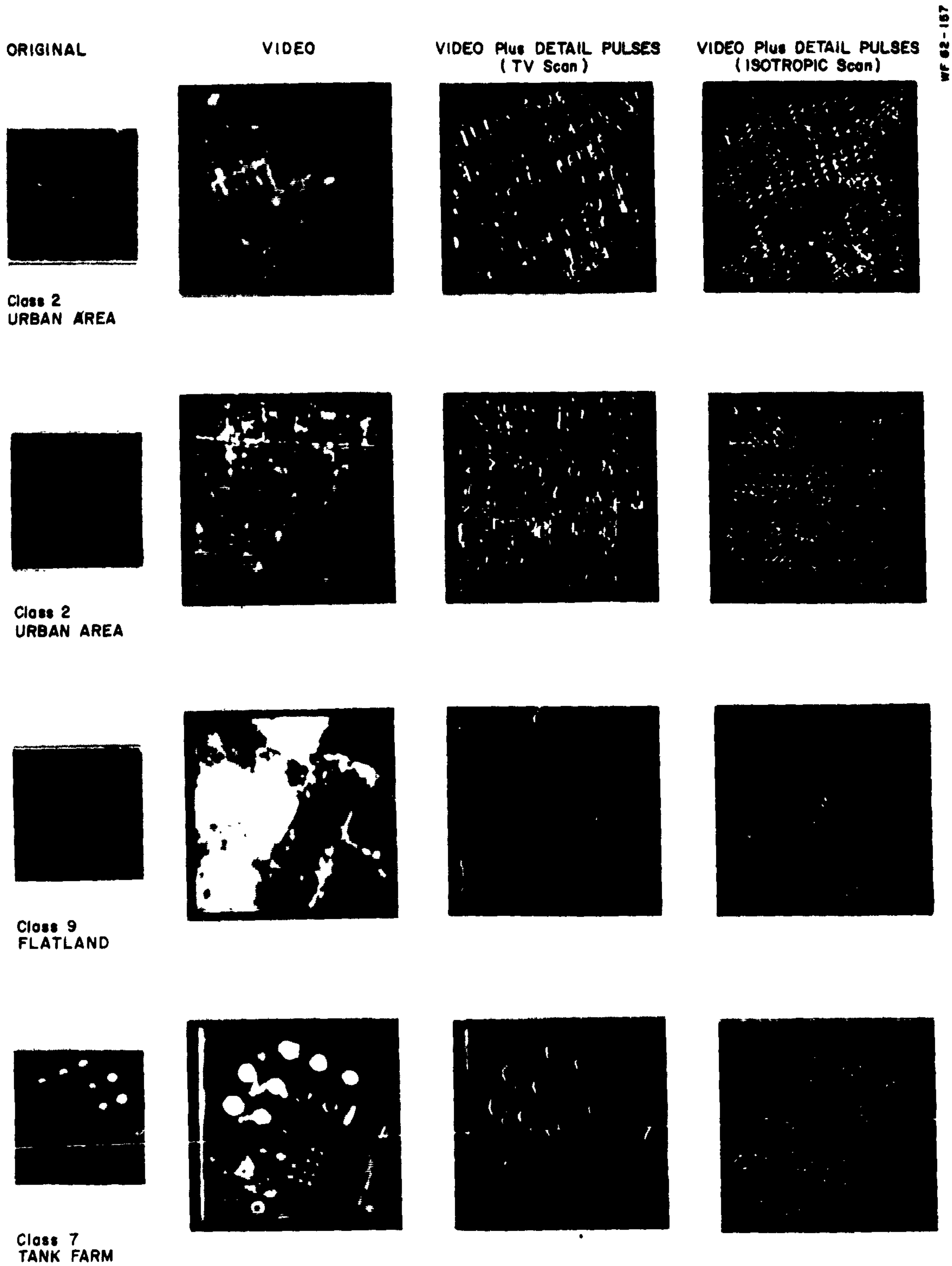


Figure 6.8 Representative Video Samples: Group II -TV and Isotropic Scans

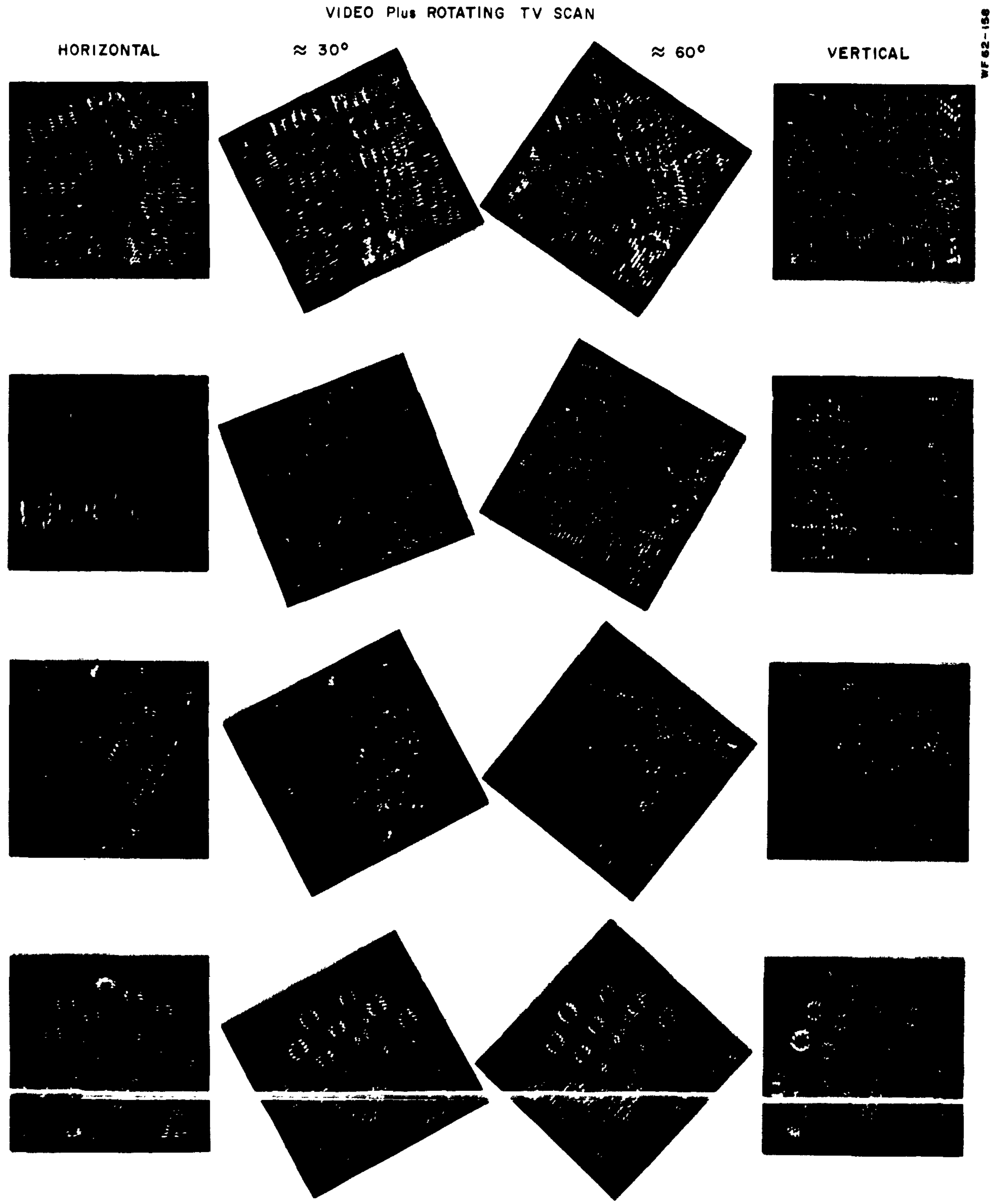


Figure 6.9 Representative Video Samples: Group II - Rotating - TV Scan

VII. CONCLUSIONS

This section will describe preliminary classification results obtained with the SATRD and recommendations for further work.

7.1 PRELIMINARY RESULTS

An initial study was made on a group of 142 samples with parameter P1, which utilizes the detail extraction circuit with an isotropic scan to measure detail per unit area. The results are displayed in the histogram of Figure 7.1 which graphs the frequency of occurrence versus the relative value of detail for each of the nine classes originally selected. It had been postulated that no single parameter would be able by itself to separate all the target classes. This statement certainly holds true for P1, however, even casual observation shows the tendency of P1 to form several subgroups. For example, note that one can separate the group consisting of urban areas and industrial complexes fairly well from a group containing all other objects by drawing an appropriate vertical line through the distributions shown in Figure 7.1.

Consider now P2, the ratio of the highest to the lowest value of photographic detail for a rotating TV scan. The distribution of P2 for the various target classes is given in Figure 7.2. This parameter alone does not appear particularly useful for classification; however, when P1 and P2 are used together, further grouping of sample points occurs indicating potential usefulness for classification.

Let us focus our attention on three target classes: urban areas, industrial complexes and a class composed of oceans and flat land. Figure 7.3 is a 2-dimensional representation of the grouping of data points for these three target classes in the P1-P2 plane. Note that urban areas and industrial complexes are indeed distinguishable from oceans and flat land, as was evident from the examination of P1 by itself. However, the simultaneous consideration of P2 is seen to additionally separate some types of industrial complexes from urban areas. This behavior has a direct physical explanation since some of the industrial complexes taken in the sample set were composed of relatively long narrow buildings, as compared to typical urban areas. These industrial complexes would be expected to show a larger variation of photographic detail as a directional scan is rotated than urban areas or industrial complexes which do not contain a significant number of long narrow facilities.

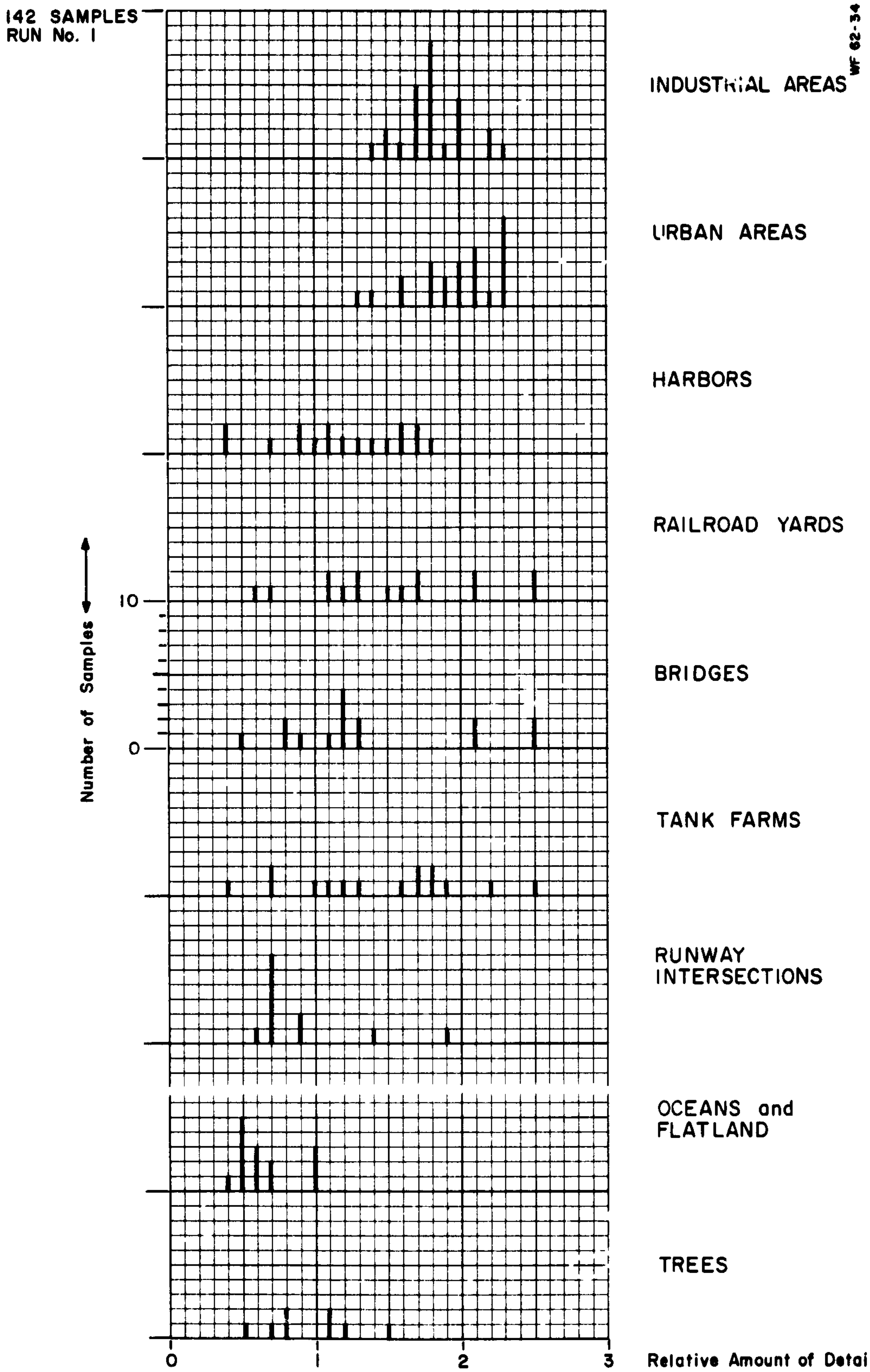


Figure 7.1 Distribution of Parameter P1

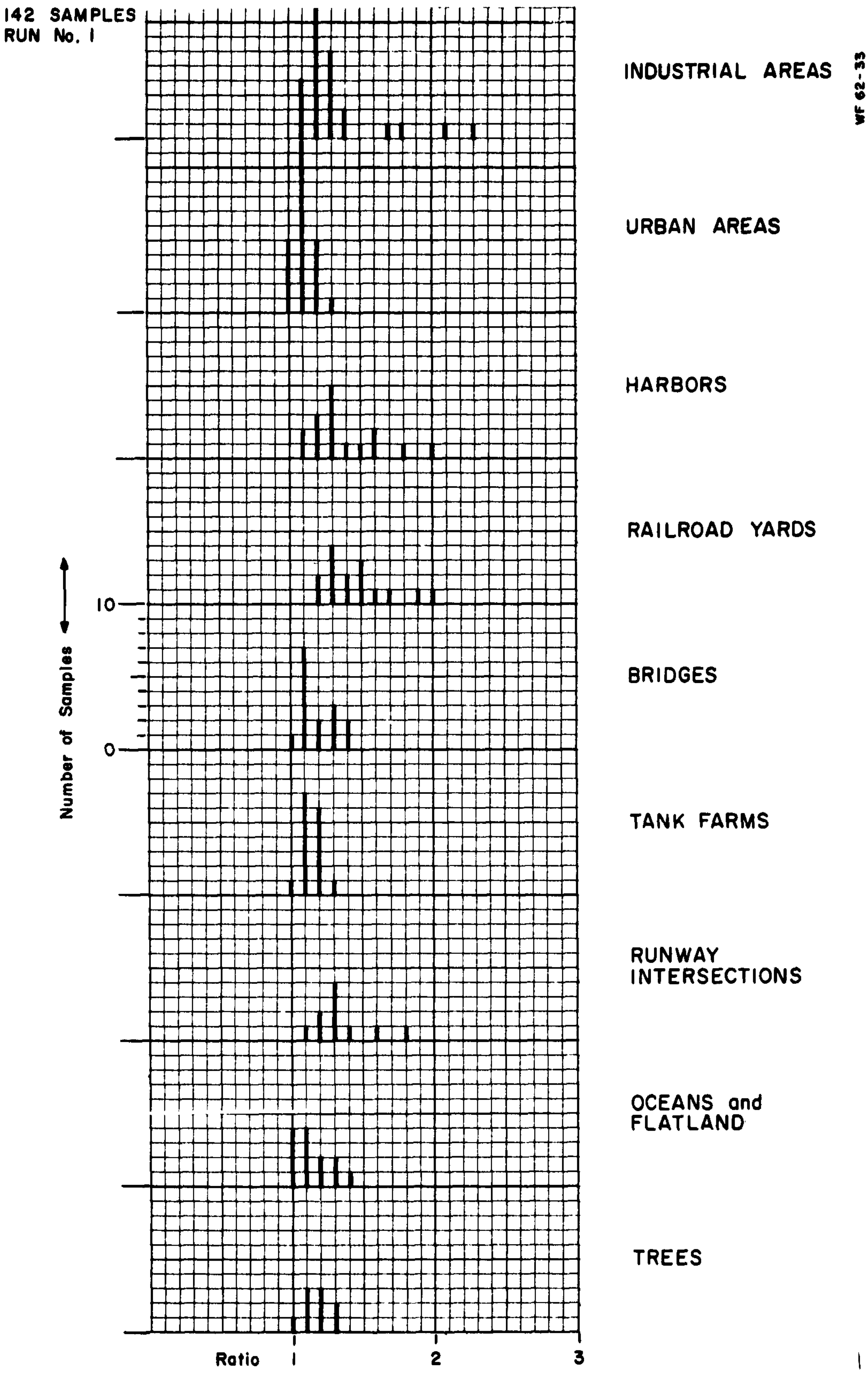


Figure 7.2 Distribution of Parameter P2

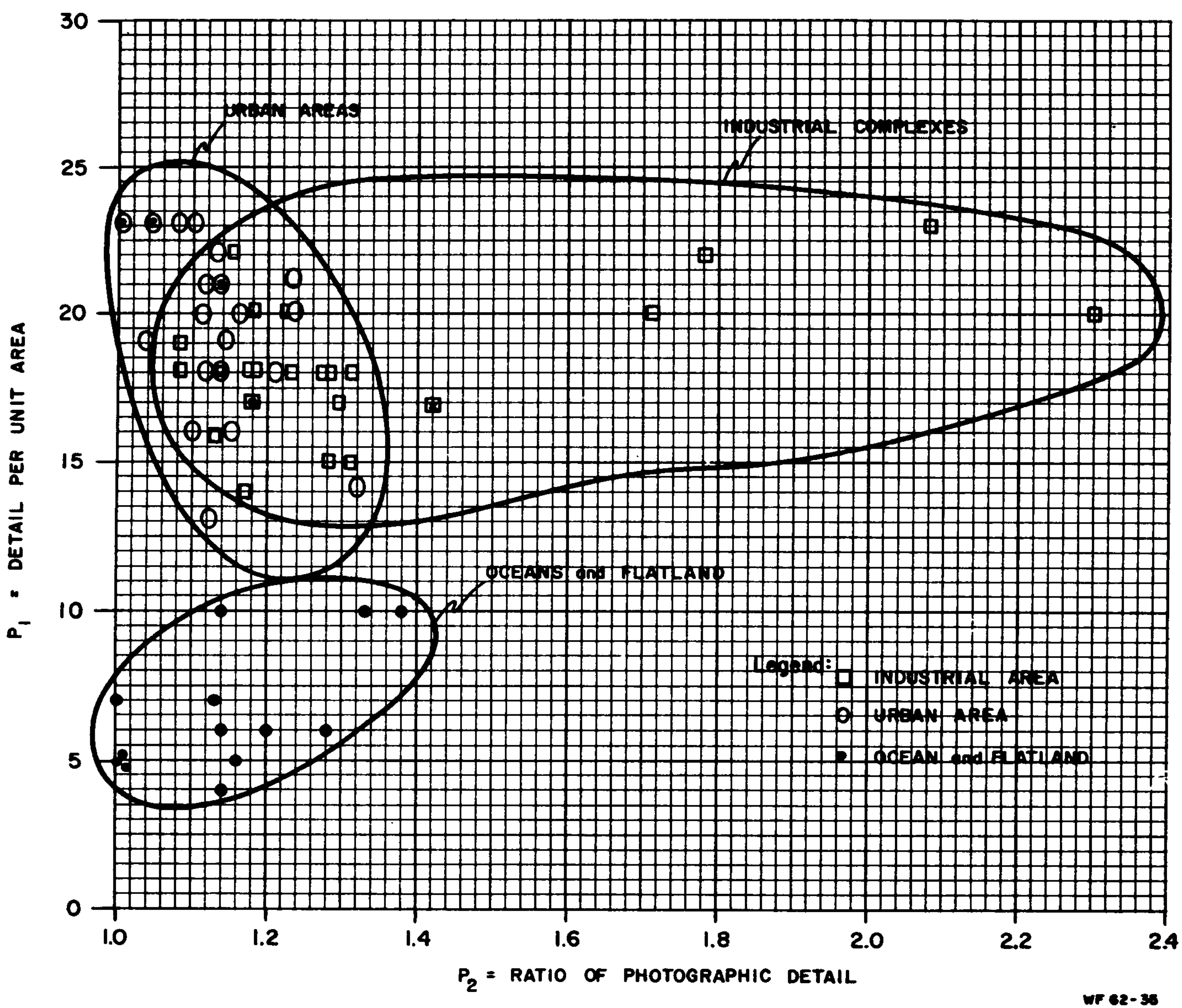


FIGURE 7.6 Distribution of P_1 and P_2 for Three Target Classes

The extension of this type of analysis to more parameters requires additional dimensions for display and is therefore less satisfactory from a pictorial geometric view point. We shall not at this point consider more parameters or target classes than used for illustration above.

Following the initial study utilizing P1 and P2 parameters, data was collected on the complete representative subset of 150 samples which was described in Section 6. As new parameters were added, additional data was collected on this same subset of samples. Classification at these early stages was then performed utilizing the truth-table approach.

The truth-table consists of an array in which each cell corresponds to a unique logical combination of quantized parameter values. Each cell is labeled with the class symbol corresponding to the sample which is represented by that particular combination of values. Decisions as to the labeling of truth table cells are made in optimum fashion, according to decision theory. If a type of target class, call it A, appears alone in a cell, all events thereafter occurring in that cell are labeled as belonging to class A. If more than one class appears in a cell, membership is assigned to that class whose highest percentage of membership is in the cell in question. For example, if 20 % of class A, 10 % of class B, and 10 % of class C are contained in a truth table cell, the cell is assigned to class A. If a tie is found in the percentage of class membership in a cell, either one of the following decision rules may be used:

(1) Non-forced decision rule, in which the cell is labeled "unclassified".

(2) Forced decision rule, in which a random choice is used to establish the labeling of the cell.

The confusion matrix of Figure 7.4 displays the results obtained for seven parameters when using the non-forced decision rule, while Figure 7.5 displays the results obtained with the identical data when the forced decision rule is invoked.

RECOGNIZED AS	INPUT CLASS									
	1	2	3	4	5	6	7	8	9	10
1. Industrial	11									
2. Urban		13								
3. Harbors			12				1			
4. Airfields				11			1			
5. Railroads	1				14					
6. Bridges						9				
7. Tanks							10			
8. Oceans								15		
9. Flatland									13	
10. Woodland				1						13
Number in Error	1	0	0	1	0	0	2	0	0	0
Number Unclassified	3	2	3	3	1	6	3	0	2	2

Recognized = 121 = 80.7 %

No. in Error = 4 = 2.7 %

Unclassified = 25 = 16.6 %

Figure 7.4 Confusion Matrix for Truth Table with 7 Parameters (Non-Forcing Decision Rule)

RECOGNIZED AS	INPUT CLASS									
	1	2	3	4	5	6	7	8	9	10
1. Industrial	12				1					
2. Urban		13								
3. Harbors			14	1			1			
4. Airfields	1			13		1	1			
5. Railroads		2			14					
6. Bridges						11				
7. Tanks	1		1			2	13			
8. Oceans	1							15		
9. Flatland									15	
10. Woodland				1		1				15
Number in Error	3	2	1	2	1	4	2	0	0	0

Recognized = 135 = 85 %

No. in Error = 15 = 15 %

Figure 7.5 Confusion Matrix for Truth Table with 7 Parameters (Forcing Decision Rule)

The confusion matrix for the group of eleven parameters previously described in Section 6 is presented in Figure 7.6, while Figure 7.7 graphically displays the improvement observed in classification as additional parameters have been added to the initial group of seven parameters.

While the improvement in classification as a function of the number of parameters has been predicted, we should be careful to recognize that the 94 °/o and 96 °/o recognition rates, for non-forced and forced decision rules respectively, represent the optimum categorization that can be obtained with the selected sample group. Unfortunately, not only does the ability to uniquely define a class improve as the number of descriptors increase, but also the number of cells in the truth table inevitably increases. The increase in truth table size spreads the samples on which learning and recognition has been taking place, thus decreasing the number of samples that fall within any one cell. Therefore, the results of Figure 7.7, while encouraging, should be accepted cautiously until larger data sets have been processed.

A second set of experiments using the above data was performed through the application of an automatic learning and recognition program. This program approximates the joint probability densities of the parameters for each of the target classes and stores the approximation in computer memory. When a new target is to be recognized and classified, the program evaluates the stored joint probability densities at the point in the parameter space corresponding to the set of parameter values observed on the particular target in question.

The first computer run constructed the probability densities from 150 targets and stored the densities at 28 selected points in parameter space. Using these 28 values and an interpolation function, a 57 percent correct recognition rate was obtained. Note that guessing would result in a 10 percent recognition rate. The confusion matrix corresponding to this computer run is shown in Figure 7.8.

When (using the same data) the probability densities were stored at 51 chosen points in parameter space and the same interpolation function was used, a greater recognition rate of 70 percent was obtained. The confusion matrix corresponding to this experiment is shown in Figure 7.9.

RECOGNIZED AS	INPUT CLASS 1	2	3	4	5	6	7	8	9	10
1. Industrial	12									
2. Urban		15								
3. Harbors			15							
4. Airfields				14						
5. Railroads	1				14					
6. Bridges						14				
7. Tanks							13			
8. Oceans								15		
9. Flatland									15	
10. Woodland										14

Recognized = 141 = 94 %

No. in Error = 1 = .7 %

Unclassified = 8 = 5.3 %

Figure 7.6. Confusion Matrix for Truth Table with 11 Parameters (Non-Forcing Decision Rule)

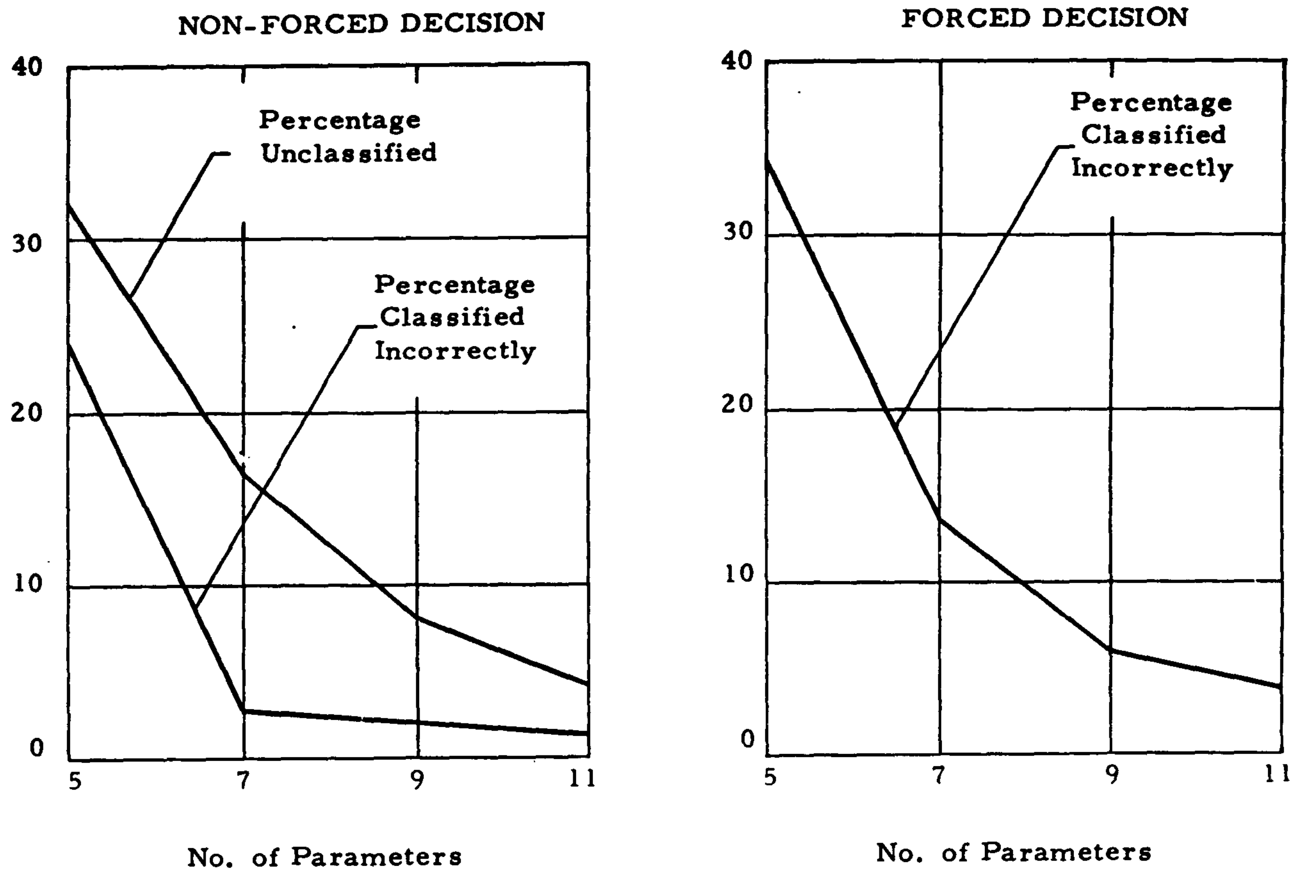


Figure 7.7 Separability vs. Number of Parameters

Recognized As	Input Class 1	2	3	4	5	6	7	8	9	10
1. Industrial	8		2	2			2			
2. Urban	1	14								
3. Harbors	1	2	8	3			1			
4. Airfields	1	1	2	7			1		3	
5. Railroads		2			11	2				
6. Bridges	4		2		1	7	1			
7. Tanks	3		2	3		1	5	1		
8. Oceans			1					13	1	
9. Flatland			3	5		1	2		2	2
10. Woodland	1		3							11

57.3 percent Correct Recognition

Figure 7.8. Confusion Matrix - 28 Stored Sample Points

Recognized As	Input Class 1	2	3	4	5	6	7	8	9	10
1. Industrial	12		1							
2. Urban		13	1							
3. Harbors	2	1	9	2					1	
4. Airfields			2	9		1	2		1	
5. Railroads		2			11	2				
6. Bridges	3				2	10				
7. Tanks	2		3	1			8			1
8. Oceans			1					14		
9. Flatland			1	2			4		8	
10. Woodland	1		3							11

70 percent Correct Recognition

Figure 7.9. Confusion Matrix - 51 Stored Sample Points

Recognized As	Input Class 1	2	3	4	5	6	7	8	9	10
1. Industrial	6		1			5	1		1	
2. Urban		14	1							
3. Harbors	2	1	7	2					3	
4. Airfields				10	1	1	2		1	
5. Railroads					9	6				
6. Bridges	2		1	1	2	8	1			
7. Tanks			2	2			9		1	1
8. Oceans								15		
9. Flatland			1	4			2		8	
10. Woodland			1						2	12

65. 3 percent Correct Recognition

Figure 7. 10. Confusion Matrix - (Learning on 100 Samples)
(Recognition of 150 Samples)

When learning was based on 100 targets of known classification and the number of targets recognized was 150, a 65 percent recognition rate was obtained. The confusion matrix corresponding to this experiment is shown in Figure 7.10. Note that some of the confusions that arise are quite reasonable in terms of the similarities of target types that were confused with one another.

While the recognition experiments described above were conducted on a limited sample size of representative targets, they are, nevertheless, indicative of the trends that can be expected. All of these experiments were performed on 11 parameters. Of course, as additional parameters obtained from area matching and from the distribution analyzer circuitry are incorporated, the probability of correct recognition is expected to increase (the error rate is expected to decrease), as already illustrated in Figure 7.7. It should also be borne in mind that the variable parameters of the recognition program were not optimized: in fact, only a single set of computer runs was made because of the limited scope of the experiments.

7.2 RECOMMENDATIONS

Feasibility of automatic target recognition using nominally vertical incidence aerial photography was studied theoretically and experimentally during this program.

It was concluded that a parametric representation of cells, each of approximately target size, of aerial photographs and a subsequent decision theoretic classification system holds greatest promise.

The statistical classification system recognizes targets as belonging to one class or another by examining the simultaneously observed parameter values of a target and comparing this set of measurements with previously encountered measurement sets to establish (a) the similarity of the measurement set to each of the previously encountered sets and (b) to evaluate the probability with which a similar previously encountered measurement set was derived from each of the target classes of interest.

The automatic extraction of approximations for the target probability densities and their automatic recognition is feasible and can be executed in a period of time compatible with the requirement for rapid processing of aerial reconnaissance photography. These techniques have been discussed in the literature and have been tested in many areas of practical application. (See reference 3 on page 10.)

The physical measurements from which a parametric description of aerial photographs can be obtained was investigated to determine the practical instrumentation achievable by circuitry processing at operating speeds compatible with the requirements on processing time for aerial photographs.

It was concluded that, although several methods of electronic processing of the video signal obtained by a variety of scan modes affords immediate target recognition techniques, these techniques are not wholly adequate to describe all target classes of interest. Parameters describing the textural properties of the area under examination on the photograph are readily obtained from electronic processing techniques. The recognition of specific shapes that serve as building blocks from which many target types are composed are not easily instrumented by electronic techniques exclusively. The combination of electronic processing and area matching, however, can yield successful recognition of specific shapes. Thus strategic targets can be recognized by electronic techniques alone, while tactical targets may require the addition of area match parameters.

The contrast sensitivity of both electronic and area matching parameters can be overcome. Local AGC and contrast normalization are techniques applicable to electronic processing, while a comparative evaluation of the input image with each of a number of stored reference shapes (masks) will reduce the contrast sensitivity of parameters obtained from area matching.

The employment of a rotating directional scan mechanism, such as the rotating TV scan, proved useful in the measurement of angles, principle directions, and other orientation sensitive parameters.

Averaging over all possible rotations and translations proved useful in describing properties of target areas in a manner insensitive to rotation and translation.

The parameter extraction techniques are effective over a ground scale range greater than 2 to 1, centered about the nominal operating scale.

Based on the experience gained with the SATRD we make the following recommendations:

1. The present equipment should be used to extract parametric descriptions of a larger selection of targets of substantially the same target classes as discussed in this report.

2. The device be modified to increase the effective illumination in the two-channel electro-optical system and area match parameters be extracted from the full range of target imagery.

3. The parameters extracted should also include those derived from the circuitry developed for the analysis of waveform statistics.

4. The parameter sets obtained in the above manner be subjected to a more exhaustive computer-aided analysis by techniques already programmed and well proven, with a view toward optimizing the variable parameters of the programs and to minimize the resulting error rates.

5. Certain modifications and additions be made to increase the degree of automaticity of parameter extraction from the already available basic physical measurements. This would serve to reduce the time required for the semiautomatic extraction of measured parameters on photographs. While only mechanizable functions are performed by humans (counting peaks on recorded waveforms, measuring time intervals on recordings, etc.), this process is extremely time consuming for the large scale analysis of pictorial data.

6. Additional parameters be devised to reduce confusions between similar subgroups of different classes and that these be implemented and incorporated in the SATRD.

The SATRD has proved the feasibility of the parametric approach to the recognition of a major group of strategic and tactical targets.

The SATRD should now be used for the extraction of data from a much larger sample set of aerial reconnaissance photography with a view towards the determination, in a statistically valid manner, of the most effective parameter set to be incorporated in future more automatic target recognition devices.

APPENDIX I

DESCRIPTION OF EXPERIMENTAL HARDWARE

The electronic portions of the SATRD system can be considered in three separate blocks which are shown in Figure I. 1 as: 1) Scan Circuitry and flying spot scanner, 2) Video Circuitry (including the photomultipliers), and 3) Parameter extraction circuitry (including the display meter and recorder).

I. 1 FLYING SPOT SCANNER AND SCAN CIRCUITRY

The flying spot scanner employed in this system is a commercially available oscilloscope, the DuMont type 401-BR, with a P24 phosphor which was chosen for its broad spectral output characteristics and short persistence. The scan circuitry provides necessary signals for deflection of the flying spot scanner and the display scope in three modes: (a) Standard TV Scan b) Rotating modified TV Scan and c) Isotropic Scan. A means is provided to control the size of the raster of all scan modes (using a single front panel "scan size pot") in such a way as to maintain constant spot velocity. A blanking circuit provides retrace blanking of the flying spot scanner, the need for which will be discussed in connection with the video circuitry. A scan indicator and protective circuit is provided to detect scan signal failure and protect the scope face against burning.

The TV Scan produces a pattern similar to that of a TV raster (Figure I. 4) on the face of the flying spot scanner and display scope. This circuitry is represented as the top half of the TV Scan block as shown in the block diagram of Figure I. 2. A more detailed block diagram of the TV Scan Circuitry is shown in Figure I . 3. The stationary TV scan is obtained from a pair of standard sawtooth generators with a horizontal frequency of 1600 cps and a vertical frequency of 17 cps, resulting in a raster containing approximately 100 lines. Synchronization of horizontal and vertical frequencies is provided to eliminate jitter. Both frequency and amplitude are simultaneously controlled by the scan size pot thereby providing a variable size raster with constant writing speed of the scanning spot.

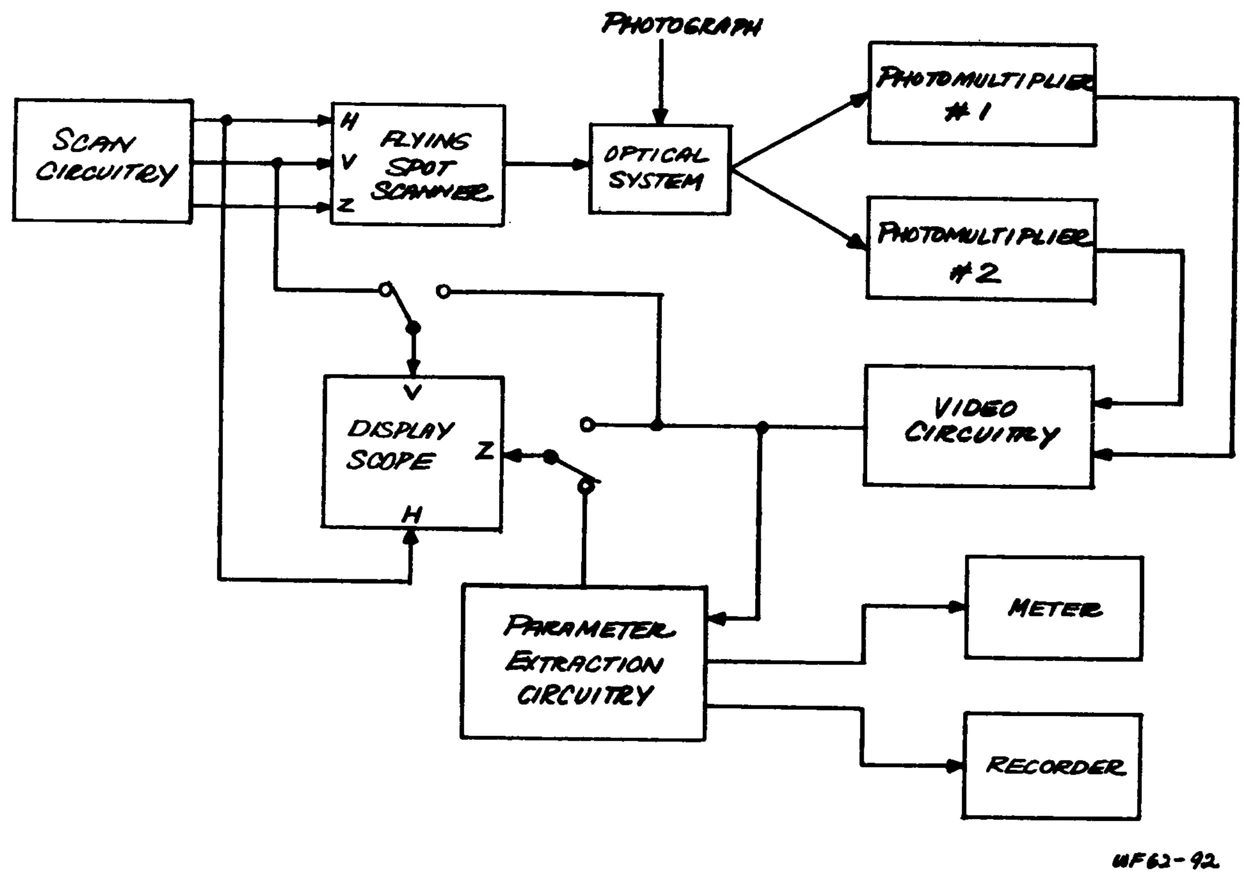


FIGURE I.1 SATRD Electronics Block Diagram

SIZE	DRAWING NUMBER	ISSUE
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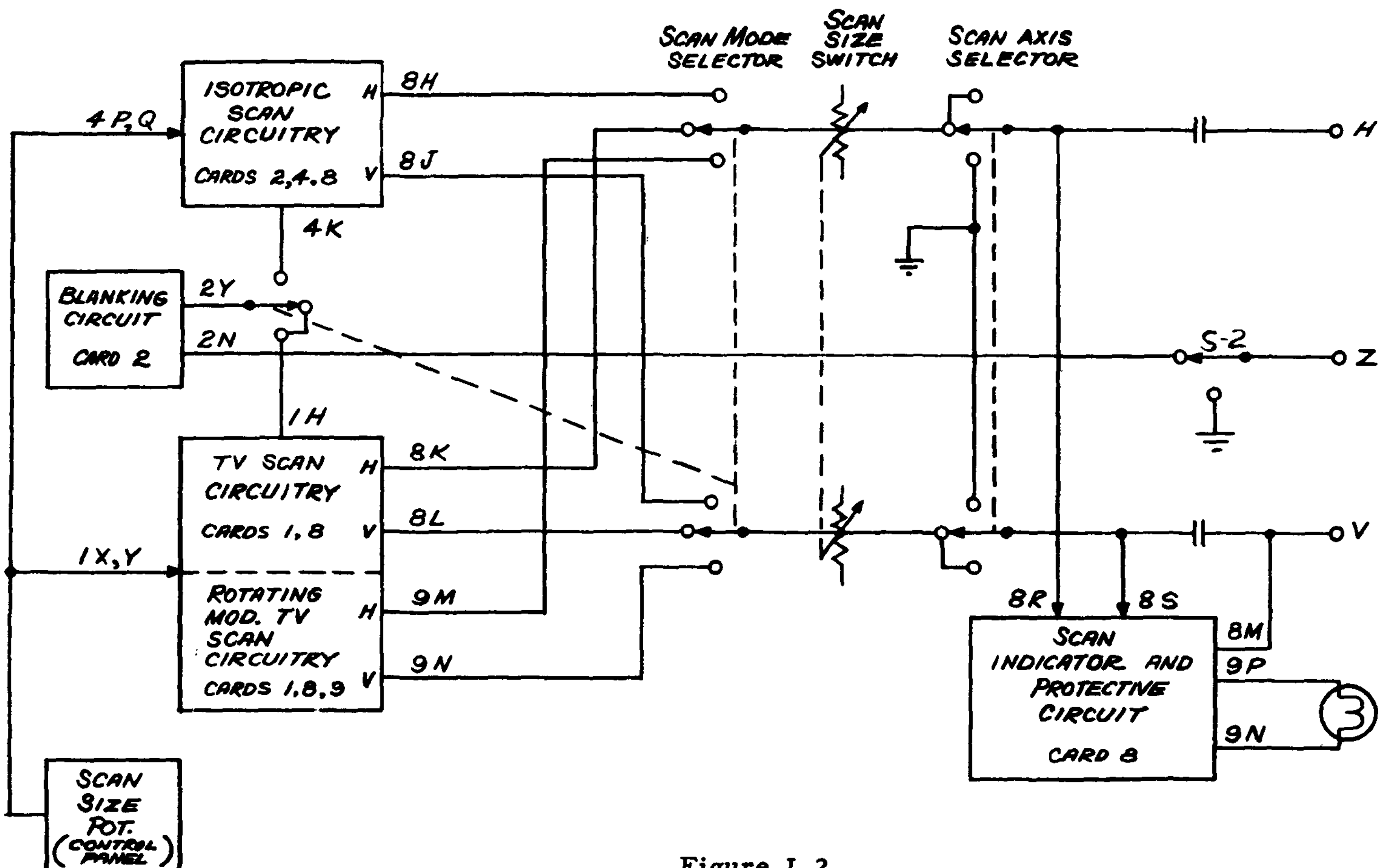


Figure I.2

AIF 62-95

TITLE SATRD
BLOCK DIAGRAM OF
SCAN CIRCUITRY

LITTON SYSTEMS, INC.
DATA SYSTEMS DIVISION
COMMUNICATION SCIENCES LABORATORY
WALTHAM, MASSACHUSETTS

DRAWN R. E. RIDLEY DATE 6-21-62
CHECKED DATE

SIZE	DRAWING NUMBER	ISSUE

REVISIONS

NO.	INITIALS	DAT

SIZE	DRAWING NUMBER	ISSUE
A	W2494 003	1

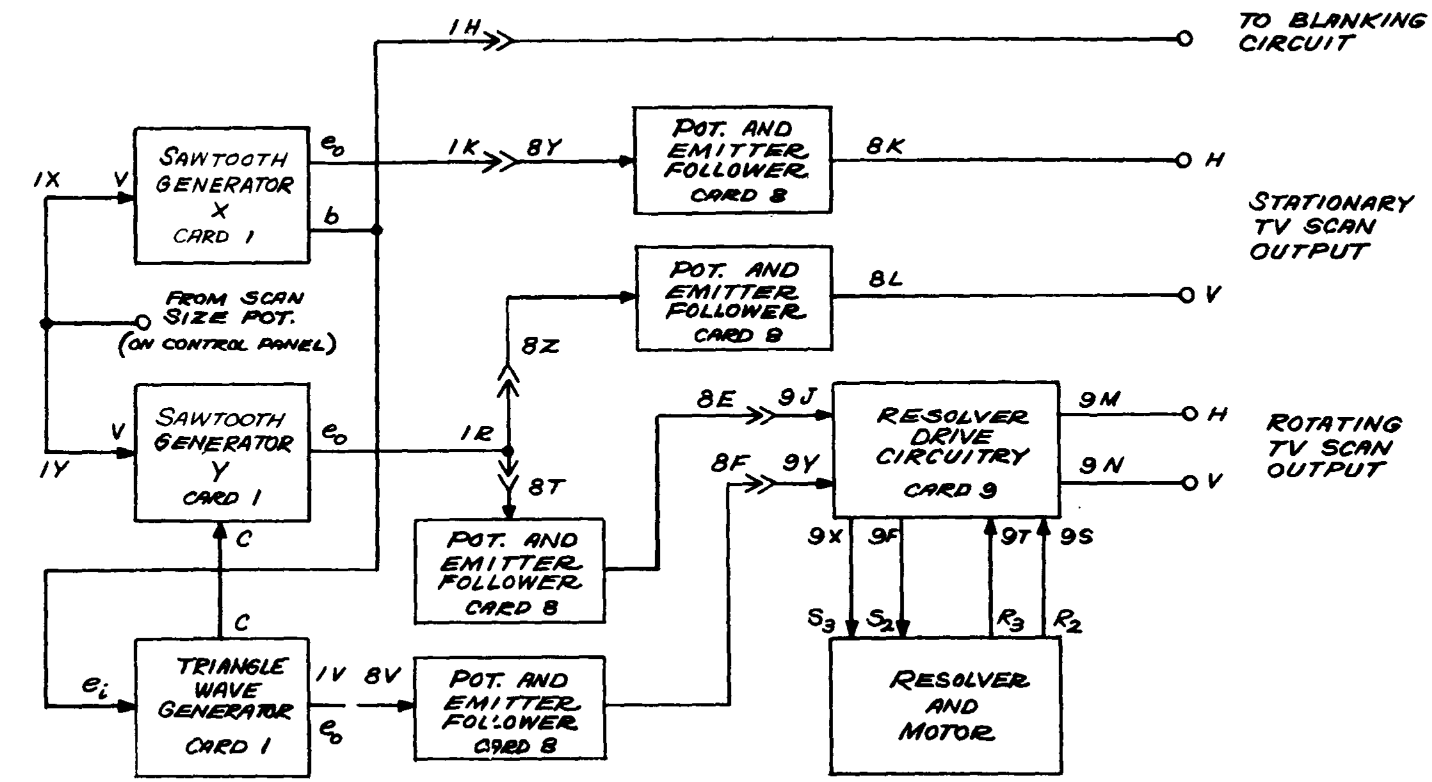


Figure I.3

WF 62-94

REVISIONS		
NO.	INITIALS	DATE

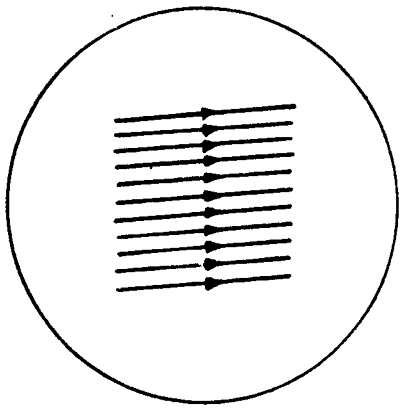
TITLE
SATRD
BLOCK DIAGRAM OF
STATIONARY & ROTATING
TV SCAN CIRCUITRY

DRAWN R. E. RIDLEY DATE 6-22-62
CHECKED DATE
APPROVED DATE

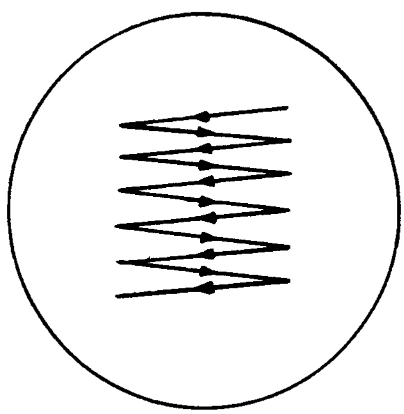
LITTON SYSTEMS, INC.
DATA SYSTEMS DIVISION
COMMUNICATION SCIENCES LABORATORY
WALTHAM, MASSACHUSETTS

SIZE	DRAWING NUMBER	ISSUE
A	W2494 003	1

WF 62-102



STANDARD TV RASTER



MODIFIED TV RASTER

FIGURE I.4 Modified TV Scan Pattern

Scan rotation is accomplished by generating deflection signals which are related to the stationary deflection signals by the following equations:

$$x' = x \cos \theta - y \sin \theta,$$

$$y' = y \cos \theta + x \sin \theta,$$

where the prime quantities indicate the rotated scan components and θ the angle of rotation. These equations are realized directly by the use of a resolver. Because of the high frequency limitation of the resolver, the horizontal sawtooth of the stationary TV scan is replaced by a triangular wave at one half the horizontal sawtooth frequency in the rotating scan. The resulting modified TV scanning pattern is illustrated in Figure I. 4. The resolver is driven at 10 cycles per minute creating a modified TV raster rotating at the same speed.

The isotropic scan generator, see Figure I. 5, consists of two triangle wave generators driven by separate sawtooth generators, operating at slightly different frequencies: f_y = 540 cps; f_x = 512 cps. The frequency of the I_x sawtooth generator is separately controllable to provide an adjustment of the frequency difference between f_x and f_y. Both frequencies may be adjusted together by means of the scan size pot in order to achieve variation in raster size while keeping writing speed and the ratio f_x/f_y constant. The isotropic scan pattern has the property that each small element of the picture is scanned in two directions, rather than in only one direction as is done by a TV type of scan. Thus, the isotropic scan tends to be non-directional in its average behaviour over the frame time of the scan generator. The repetition rate of the isotropic scan is equal to the difference of the triangle wave generators; i. e., 28 cps for the frequencies stated above. The scanning pattern consists of straight line segments which cover the viewing area and have two different scanning directions (each segment is actually traced out in both directions along the line during a frame). The method of generating the isotropic scan and the appearance of the raster are illustrated in Figure I. 6.

I. 2 VIDEO CIRCUITRY

The block diagram of the video circuitry, Figure I. 7, shows the basic components of this part of the system:

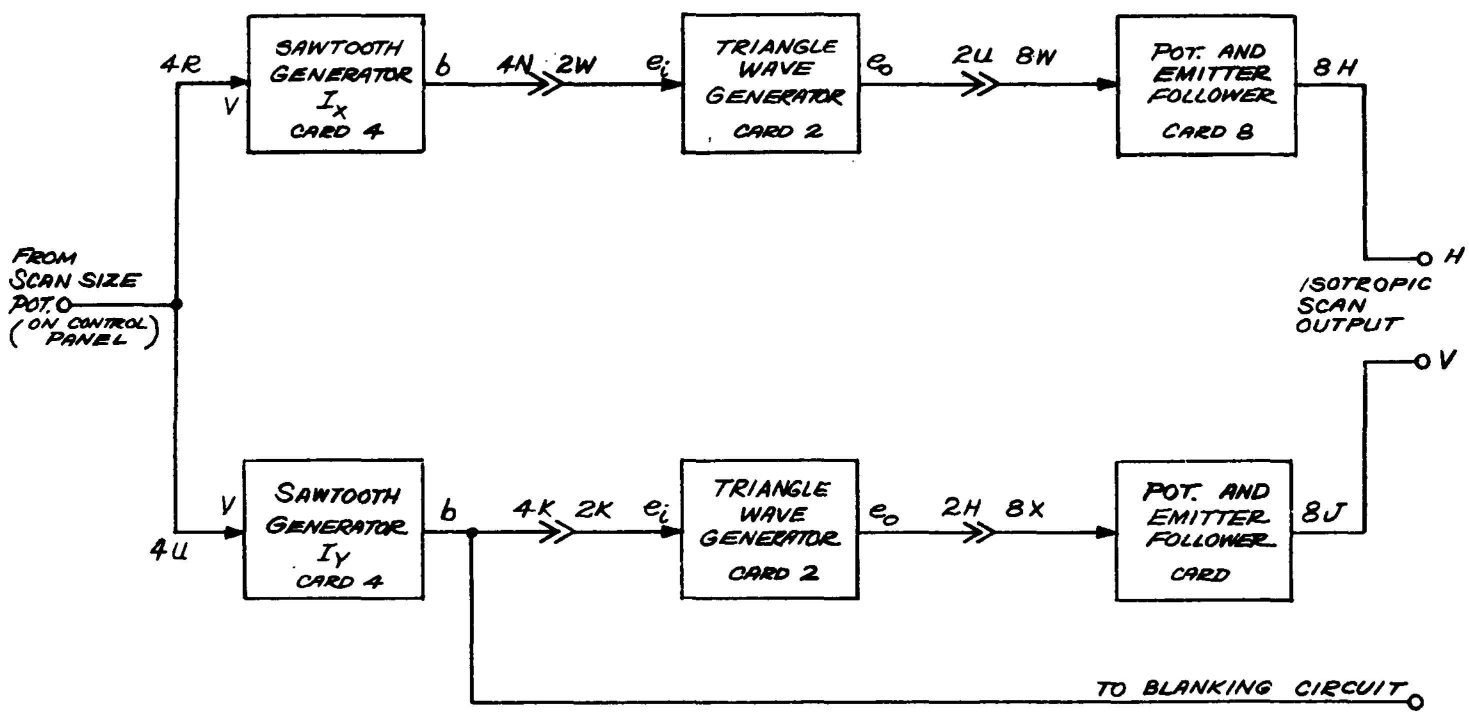


Figure I.5

WF 62-93

REVISIONS		
NO.	INITIALS	DATE

TITLE SATRD
BLOCK DIAGRAM OF
ISOTROPIC SCAN CIRCUITRY

LITTON SYSTEMS, INC.
DATA SYSTEMS DIVISION
COMMUNICATION SCIENCES LABORATORY
WALTHAM, MASSACHUSETTS

DRAWN	R E RIDLEY	DATE 6-22-62	SIZE	DRAWING NUMBER	ISSUE
CHECKED		DATE	A	W 2494 004	/
APPROVED		DATE			

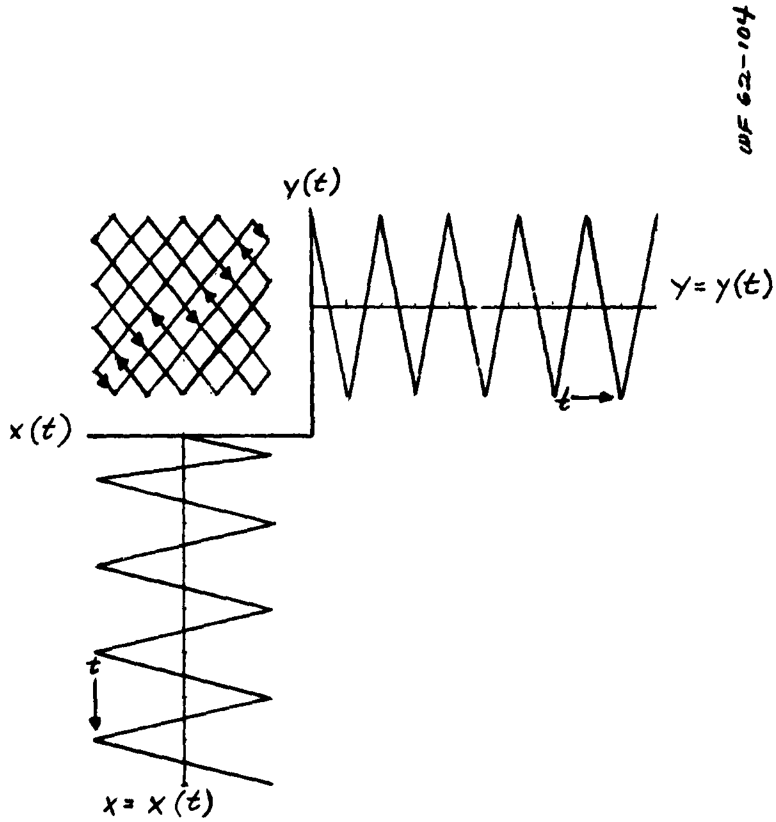


FIGURE I. 6 Isotropic Scan Formed by Triangular Waves

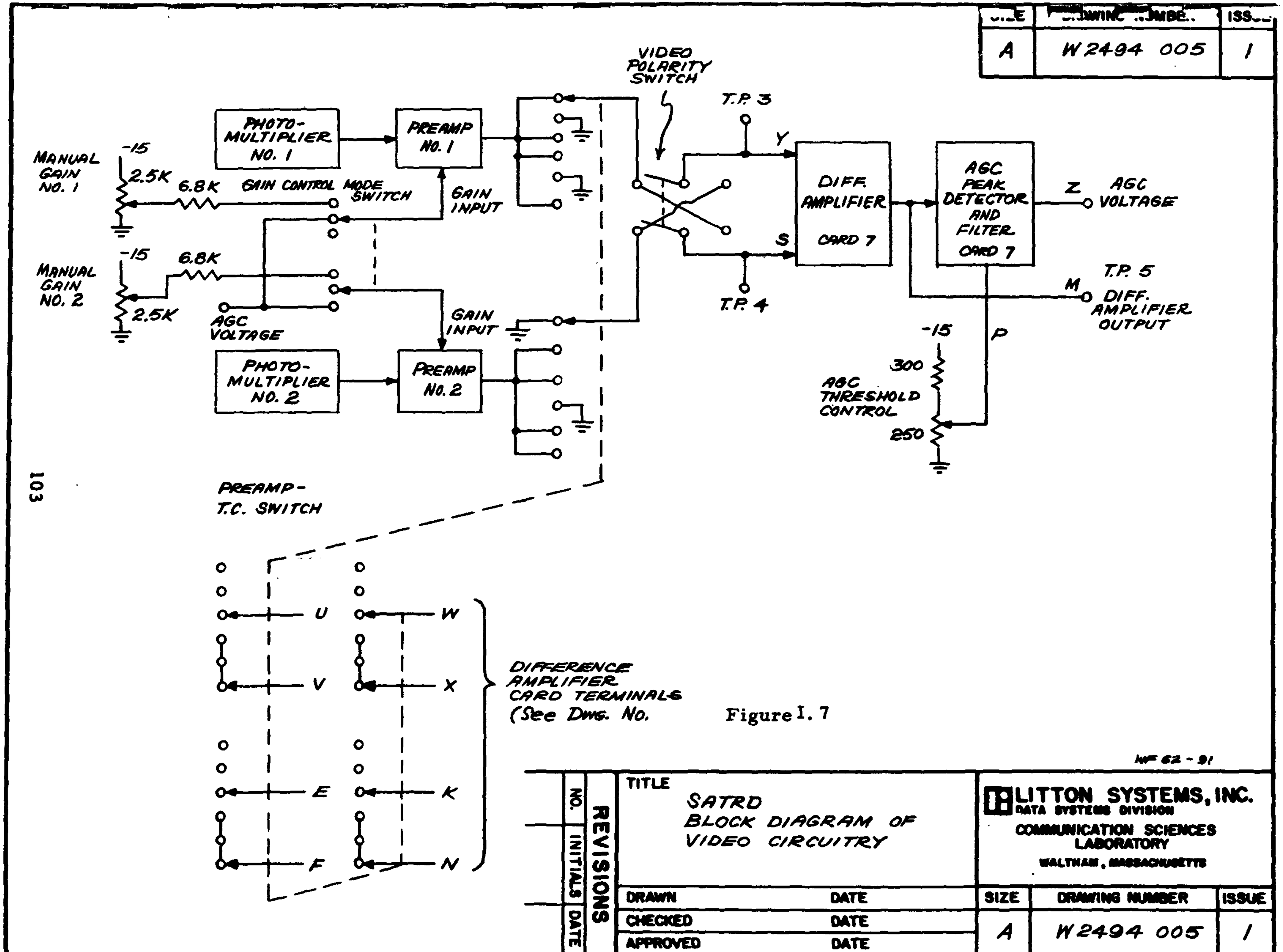

SIZE
A
DRAWING NUMBER
W2494 005
ISSUE
1
VIDEO POLARITY SWITCH
T.P. 3
T.P. 4
Y
S
PHOTO-MULTIPLIER NO. 1
PREAMP NO. 1
PHOTO-MULTIPLIER NO. 2
PREAMP NO. 2
MANUAL GAIN NO. 1
MANUAL GAIN NO. 2
-15
2.5K
6.8K
GAIN CONTROL MODE SWITCH
GAIN INPUT
AGC VOLTAGE
DIFF. AMPLIFIER CARD 7
AGC PEAK DETECTOR AND FILTER CARD 7
Z
AGC VOLTAGE
T.P. 5
M
DIFF. AMPLIFIER OUTPUT
P
300
250
ABC THRESHOLD CONTROL
PREAMP-T.C. SWITCH
U
V
E
F
W
X
K
N
DIFFERENCE AMPLIFIER CARD TERMINALS (See Dwg. No.
WF 62 - 91
REVISIONS
NO.
INITIALS
DATE
TITLE
SATRD BLOCK DIAGRAM OF VIDEO CIRCUITRY
DRAWN
DATE
CHECKED
DATE
APPROVED
DATE
LITTON SYSTEMS, INC.
DATA SYSTEMS DIVISION
COMMUNICATION SCIENCES LABORATORY
WALTHAM, MASSACHUSETTS

Figure I.7

a) Photomultipliers and preamps
b) Difference amplifier
c) Automatic gain control circuits

The video circuitry can be operated as a single channel system using either photomultiplier and its preamp with either manual or automatic gain control or as a dual channel system using both photomultipliers and manual gain controls. In the dual channel mode the polarity of the output signal can be inverted by reversing the difference amplifier input connections (using the switch at the input to the difference amplifier). All gain controls and video mode selector switches are available on the SATRD control panel shown in Figure I. 19.

The AGC circuit adjusts the system gain to a dark level output of -11 volts. Thus, the boundary detection process is normalized for the wide range of gray scales encountered in going from one photograph to another, or from one region on a photograph to a different region.

The AGC circuit controls the gain of the combined preamp-difference amplifier. Gain control action is achieved by a diode placed across the input to the preamp. A negative peak detector on the output of the difference amplifier monitors the output signal. This voltage is then amplified and filtered and fed back to the controlling diode for AGC action. The peak detector is a permanent part of the difference amplifier card and its output can be fed to either preamp. Manually set voltages control the gain of the preamps when AGC is not used. In its usual mode of operation, the peak detector operates on the negative spike created during retrace blanking of the flying spot scanner.

I. 3 PARAMETER EXTRACTION CIRCUITRY

The parameter extractor, as shown in Figure I. 8, consists of four basic extraction circuits (a) a Detail Extraction circuit, (b) a Uniformity of Detail circuit, (c) a Degree of Area Match circuit (for optical area matching) and (d) the Voltage Range Indicator circuit. The outputs of these basic circuits are utilized to obtain the parameters used for target classification.

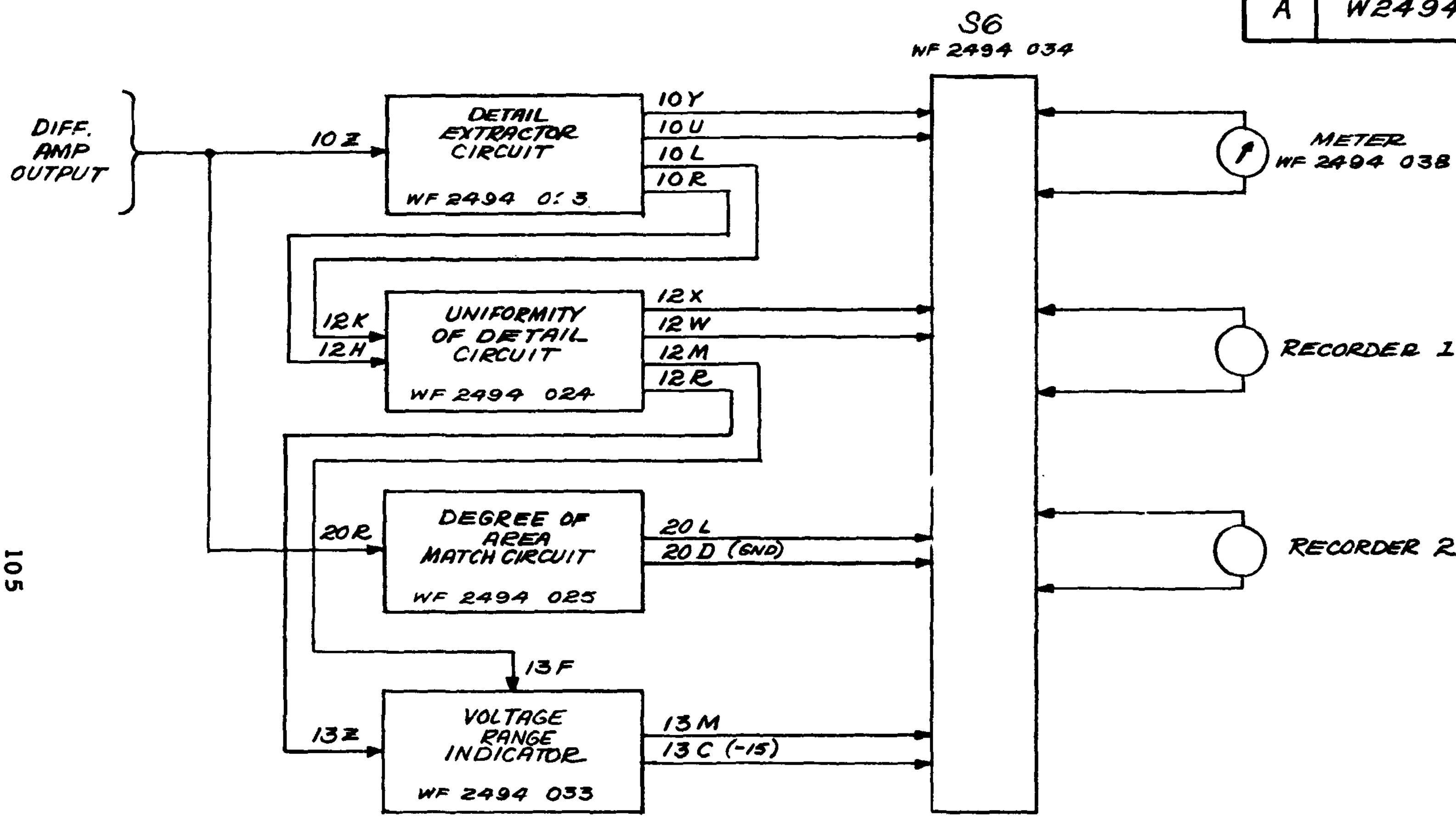


Figure I. 8

SIZE	DRAWING NUMBER	ISSUE
A	W2494 006	2

WF 62-141

REVISIONS		
NO.	INITIALS	DATE

TITLE SATRD BLOCK DIAGRAM OF BASIC PARAMETER EXTRACTOR CIRCUITRY

DRAWN	P-R	DATE	9/10/62
CHECKED		DATE	
APPROVED		DATE	

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SIZE	DRAWING NUMBER	ISSUE
A	W2494 006	2

One output of the detail extractor (see block diagram, Figure I. 9) is a $5\mu s$ pulse for each gray level transition encountered as the spot scans across the photograph. This output may be applied to the Z axis of the display scope with, or in place of, the raw video signal, and serves as an aid in both trouble shooting and evaluation of new parameters. The second output is a dc voltage obtained by passing the $5\mu s$ pulses through a low pass filter. This output is the one indicated on the output meter. The Schmitt Trigger firing level is set by a screwdriver pot adjustment during alignment and, as discussed earlier, is equivalent to setting a threshold on the change of gray level which defines a boundary crossing on the photograph.

The block diagram of the Uniformity Circuit is shown in Figure I.10 This circuit produces a voltage proportional to the instantaneous interval between the $5\mu s$ pulses from the detail extractor. It also averages this voltage over a complete frame and generates a second output voltage which is proportional to the average of the absolute value of the difference between the instantaneous interval and the average interval. Thus the second output is a measure of the uniformity of the detail spacing in the photograph. Note that if a directional scan (such as a TV scan) is employed, this circuit measures uniformity of detail spacing <u>in the direction</u> of the scan. This sensitivity of output readings to the direction of scan is utilized in extracting further classification parameters.

The Voltage Range Indicator circuit (VRI) is used to determine the distribution of detail intervals (the intervals between detail pulses). The block diagram is shown in Figure I. 11. The detail intervals are first converted to voltage levels in the uniformity circuit previously described, and the resulting stepwise waveform is then analyzed by the VRI circuit.

The VRI circuit determines when the input waveform is within $\pm\ \delta/2$ of a preset voltage V_R. Both V_R and δ are set by panel controls. Two outputs are available. One of these presents a constant area pulse for each time a detail interval is within the specified limits. The other output provides a "1" signal during the entire interval that the input signal is within the specified limits, and a "0" signal at other times. The constant area pulses can be averaged to obtain the number of pulses per frame.

SIZE	DRAWING NUMBER	ISSUE
A	W2494 007	1

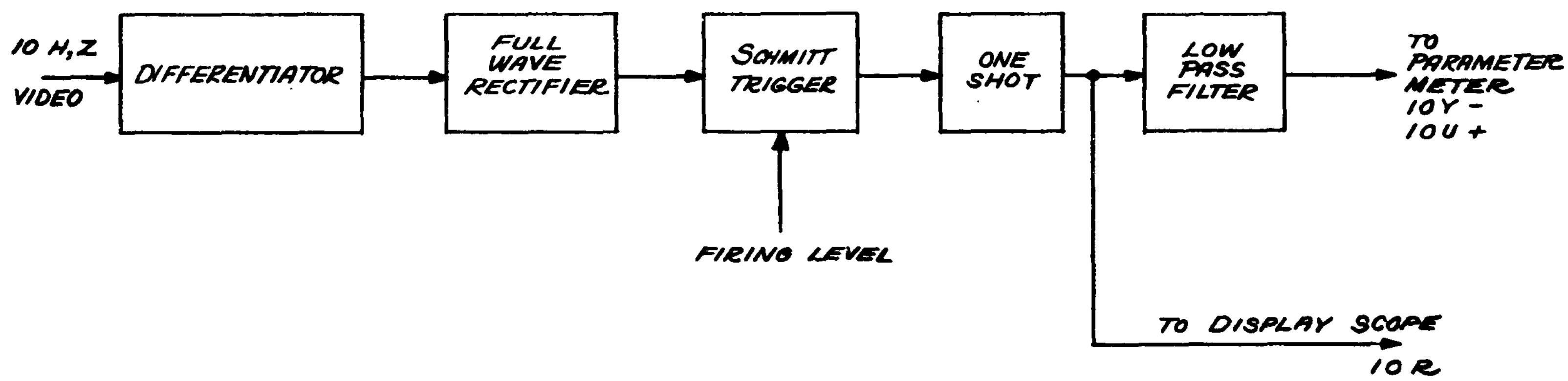

Figure I.9

WF 62- 97

REVISIONS		
NO.	INITIALS	DATE

TITLE
SATRD
DETAIL EXTRACTOR
BLOCK DIAGRAM

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DRAWN	R=RIDLEY	DATE	6-25-62
CHECKED		DATE	
APPROVED		DATE	

SIZE	DRAWING NUMBER	ISSUE
A	W2494 007	1

SIZE	DRAWING NUMBER	ISSUE
A	W2494 008	/

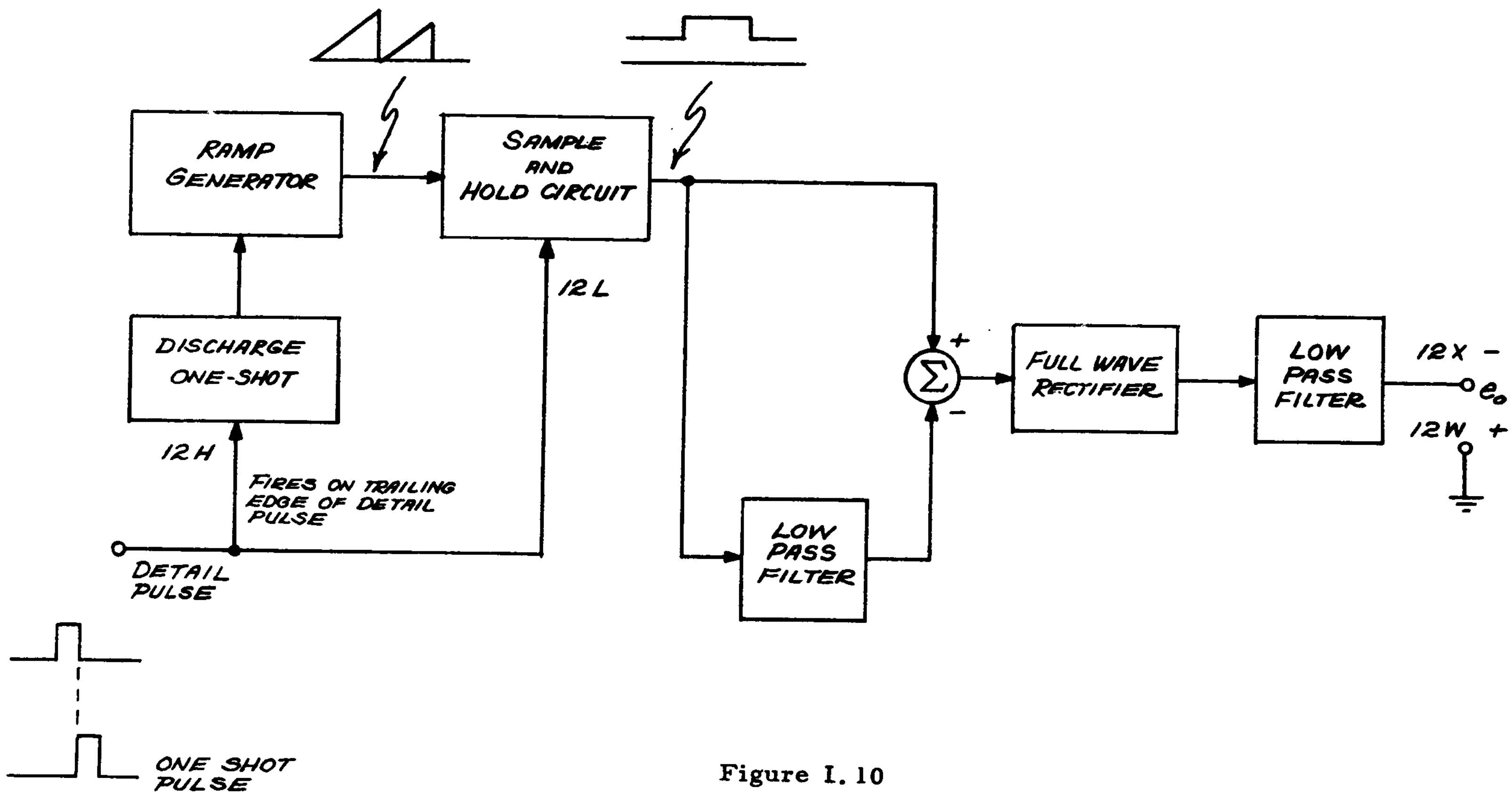

Figure I. 10

WF 62 - 96

REVISIONS		
NO.	INITIALS	DATE

TITLE SATRD BLOCK DIAGRAM OF UNIFORMITY CIRCUIT

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DRAWN	R. E. Ripley	DATE	6-25-62
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APPROVED		DATE	

SIZE	DRAWING NUMBER	ISSUE
A	W 2494 008	/

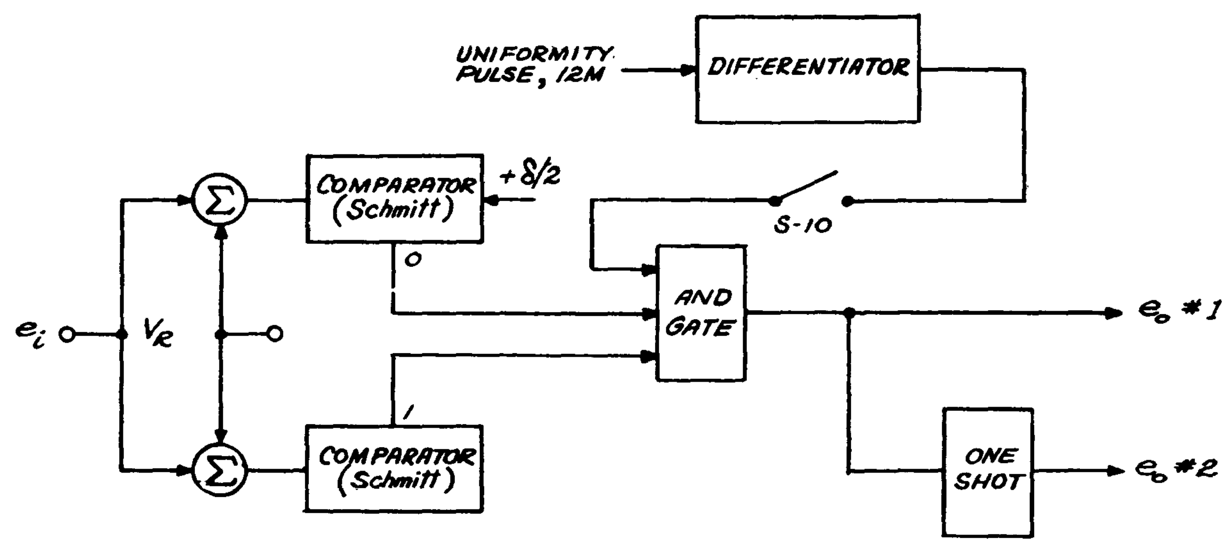

Figure I. 11

WF 62-149

REVISIONS		
NO.	INITIALS	DATE

TITLE SATRD
VOLTAGE RANGE INDICATOR
BLOCK DIAGRAM

DRAWN	R. Ridley	DATE	9/24/62
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APPROVED		DATE	

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SIZE	DRAWING NUMBER	ISSUE
A	W2494 039	1

The degree of area match circuit (Figure I. 12) produces an output voltage proportional to the percentage time the video signal is above a threshold value. This circuit indicates the extent to which a specific shaped image has been matched throughout the region of a photograph scanned by the raster.

The two-channel optical system as described in Section IV and illustrated in Figure 4. 7 is used in the SATRD. The two-colored mask is made of Wratten type 43A (purple) and type 12 (yellow) gelatin filter material. These filter types were chosen for negligible crosstalk and spectral transmissivity peaks which lie well within the spectral output curve of the P24 phosphor utilized in the flying spot scanner as indicated in Figure I. 13.

Changes in image scale for area matching are conveniently performed by moving lens L2 with a focussing handwheel (Figure I. 14).

All angular orientations of the image are examined in the determination of the degree of area match between the mask image and the photograph. The mask holder is motor driven at 6 1/2 revolutions per minute. With a TV scan frequency of 17 frames per second, there is less than 2. 3° of angular mask motion per frame.

I. 4 PHYSICAL LAYOUT OF MAIN FRAME

An exterior view of the device is shown in Figure I. 14 and a photograph of the SATRD set up for data collection and target recognition is shown in Figure A. 15. A light-tight cabinet encloses those parts of the projection optical system (Figure I. 16) which must be operated in a dark environment to permit operation of the device under normal room ambient lighting. The cabinet is mounted on casters for easy movement and the lower cabinet panels are fastened with thumb screws for convenient access to components. A light hood covers the upper part of the cabinet to permit convenient access to the transport mechanism (Figure I. 16) on which aerial film is loaded. A focusing wheel below the light hood is used to focus the image of the raster into the plane of the aerial film when extracting electrical parameters. When extracting electro-optical parameters the lens L2 is lowered to adjust the size of the mask image that is to be rotated and scanned over the film area.

SIZE	DRAWING NUMBER	ISSUE
A	W2494 009	1

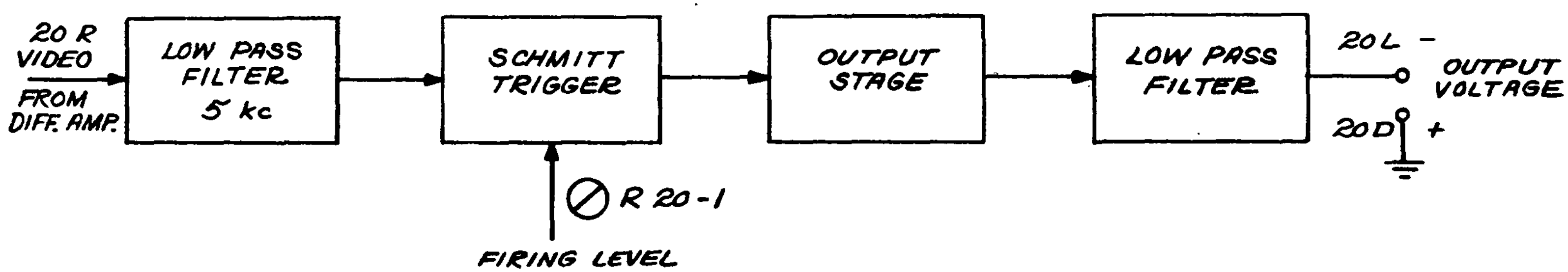


Figure I. 12

WF 62-98

REVISIONS			TITLE SATRD DEGREE OF AREA MATCH BLOCK DIAGRAM		LITTON SYSTEMS, INC. DATA SYSTEMS DIVISION COMMUNICATION SCIENCES LABORATORY WALTHAM, MASSACHUSETTS		
NO.	INITIALS	DATE	DRAWN R E RIDLEY	DATE 6-25-62	SIZE	DRAWING NUMBER	ISSUE
			CHECKED	DATE	A	W2494 009	1
			APPROVED	DATE			

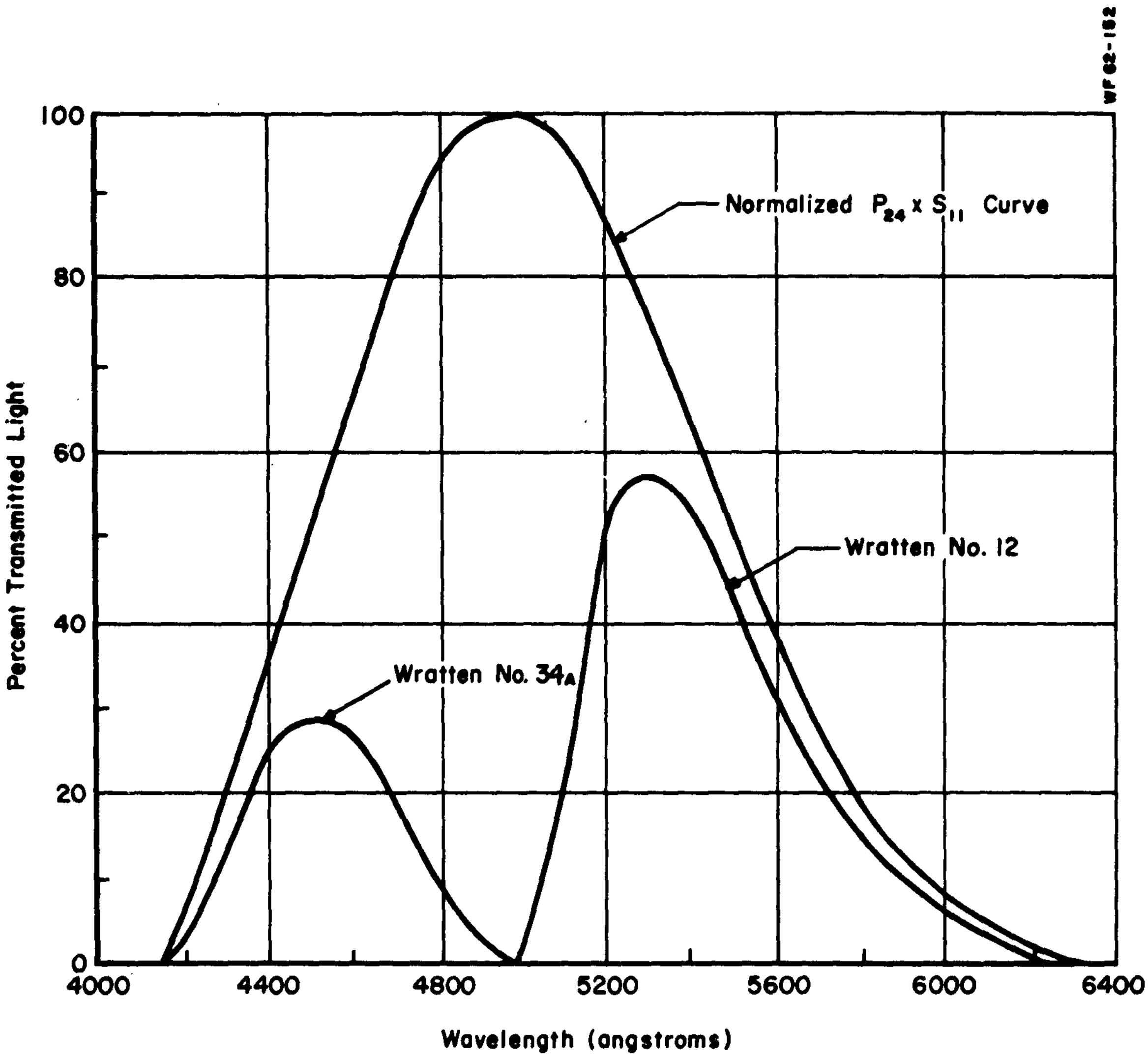
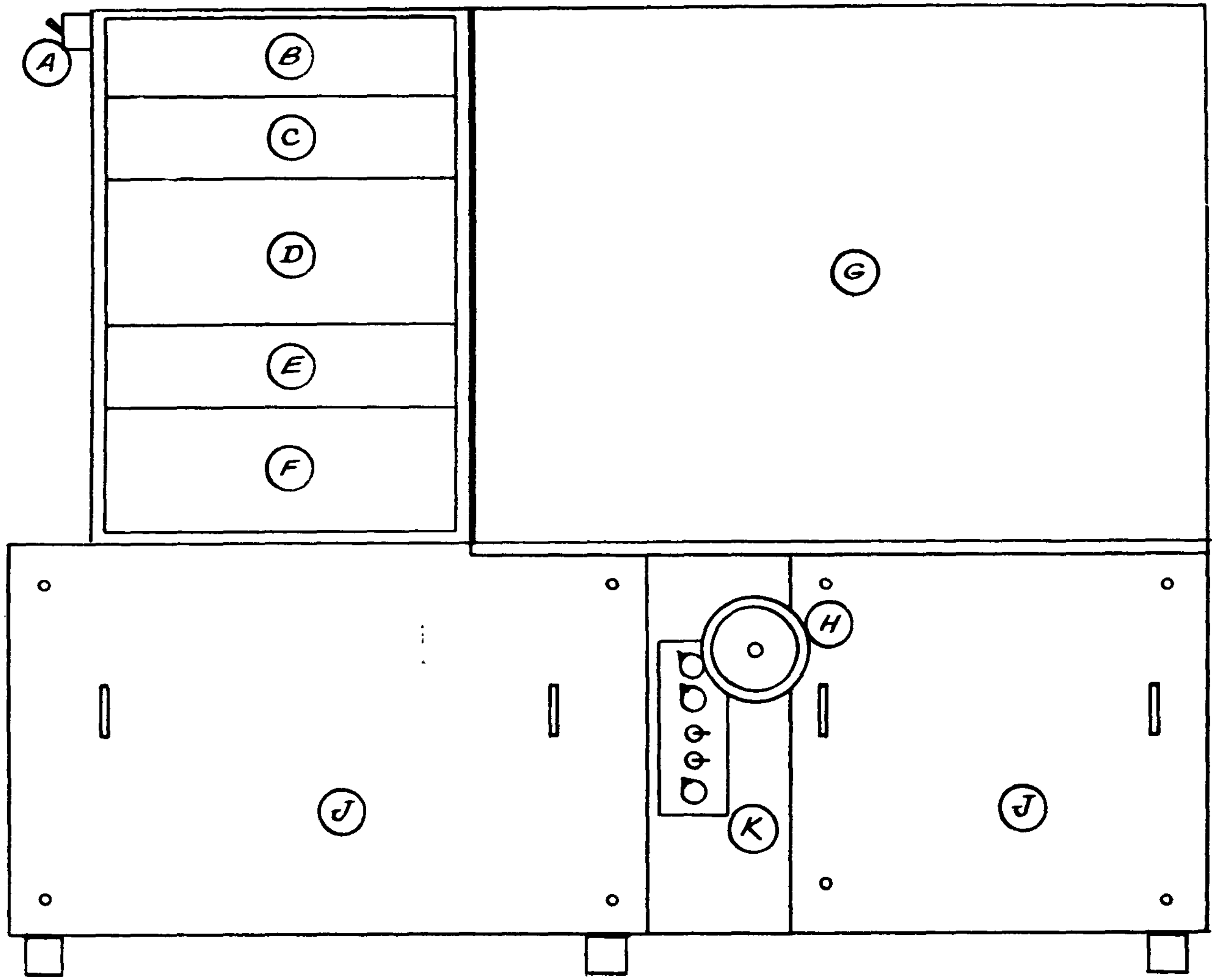


Figure I. 13 Two Color System Response

SIZE	DRAWING NUMBER	ISSUE
A	W 2494 026	1



A. MAIN POWER SWITCH

B. CONTROL PANEL

C. CARD FRAME

D. RESOLVER

E. LOW VOLTAGE POWER SUPPLY

F. HIGH VOLTAGE POWER SUPPLY

G. LIGHT HOOD

H. FOCUSING WHEEL

J. QUICK-ACCESS PANELING

K. SCANNER REMOTE CONTROLS.

Figure I.14

WF 62-99

REVISIONS		
NO.	INITIALS	DATE

TITLE
EXTERIOR VIEW OF SATRD

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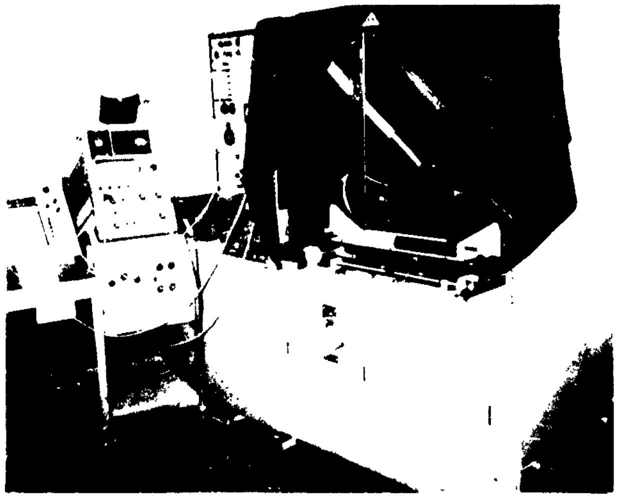
DRAWN	R E Ridley	DATE	6-29-62
CHECKED		DATE	
APPROVED		DATE	

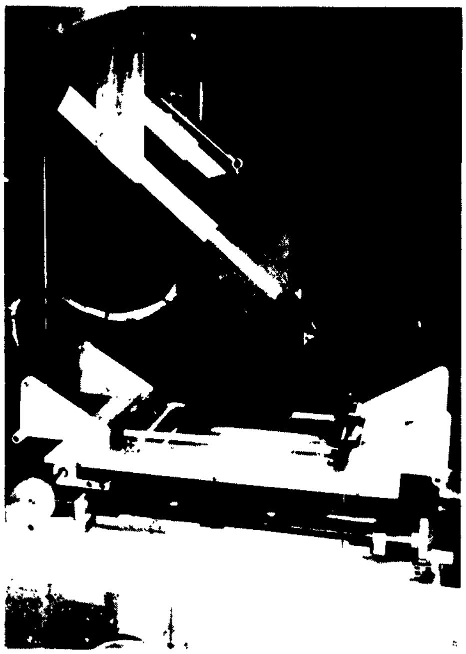
SIZE	DRAWING NUMBER	ISSUE
A	W2494 026	1

WFCL-50



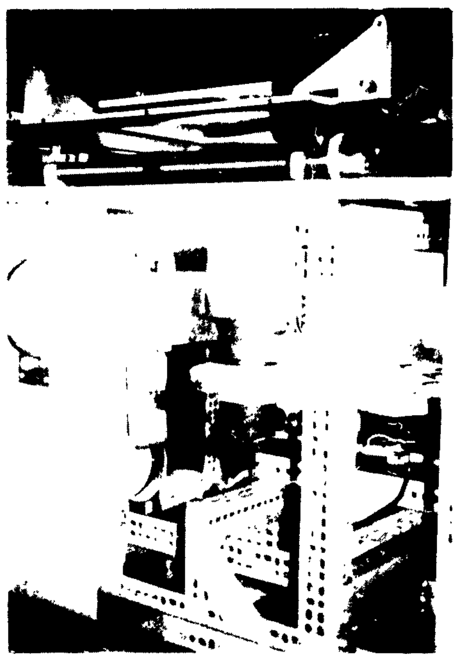
SATRD set up for Data Collection

Figure I. 15



Film Transport and
Video Transducer Box

Figure I. 16



Flying Spot Scanner,
Optics and Mask Turret

Figure I. 17

A cutaway simplified view of the arrangement of major components within the cabinet is shown in Figure 5. 1.

The flying spot scanner used in this system is a DuMont 401-BR oscilloscope, which is mounted within the cabinet so that the face of the scanner CRT is in the most convenient position for the required optical system.

An optical system is provided to perform optical area matching, using a series of two-color masks for the different target areas under consideration. The optical system contains a mirror which bends the optical path through 90 degrees to permit a horizontal film plane to be utilized for visual inspection as well as for parameter measurement. The mask turret is used to position various two-color masks between the collimating lenses in the optical system when area matching parameters are extracted, while the mask rotator spins the mask about its midpoint. See Figures 5. 1 and I. 17.

The film transport (Figures 5. 1 and I. 16) is used to move the film across a transparent plate on which images of the scanning spot (for electrical parameters) or images of the two-color masks (for optical parameters) are focused. The transport is positioned along two horizontal axes by means of handwheels to permit selected regions of photographic frames to be centered on the optical axis.

Video Pickup or Photomultiplier Unit (Figures 5. 1 and I. 16) A photomultiplier unit is mounted above the transport mechanism. The entire assembly slides on rails so that it can be moved out of the main viewing area to permit operator selection of the area to be measured. This sliding assembly contains the following items:

1) A collecting lens which intercepts the beam of light transmitted through the transport and film.

2) A partially silvered mirror which divides the collected beam into the two photomultiplier channels.

3) Two DuMont type 6292 photomultiplier tubes, one for each channel.

4) Two filter holders which are placed in front of the photomultiplier tubes. One filter holder contains a Wratten type 34A filter and the other contains a Wratten type 12.

5) Two video preamplifiers. These preamplifiers are placed close to their respective photomultipliers to minimize noise pickup. Gain balancing controls (Figure I. 18) for the preamplifiers are located on the main control panel.

I.5 ELECTRONIC RACK LAYOUT

An electronics rack, Figure I. 18, is mounted on the equipment cabinet to the left of the light hood. This rack contains the following major components (from top to bottom):

The control panel, Figure I. 19, contains the necessary controls, test points and indicators for operation of the scan, video, and parameter extraction circuitry. A brief description follows:

1. Scan Mode Selector Switch - This is a three position switch which selects either a stationary TV scan, isotropic scan, or rotating modified TV scan.

2. Scan Size Switch - A six position switch provides scaling of the scan size by six equal increments. This control does not affect scan frequencies but simply scales magnitude of scan signal.

3. Scan Size Potentiometer - Control of scan frequencies is performed with this potentiometer to change size of scanning pattern while keeping the writing speed constant.

4. Scan Axis Selector Switch - This three position switch allows choice of: the normal raster (in position marked "both"), X deflection only, and Y deflection only. When only one of the axes is selected, the other input to the flying spot scanner is grounded.

5. Scan Indicator Light - This pilot light remains turned on whenever deflection signals are present at the flying spot scanner input terminals. The light is turned off automatically when no deflection signals are present and simultaneously a relay is energized to apply a protective deflection signal to avoid burning the face of the scanner CRT.

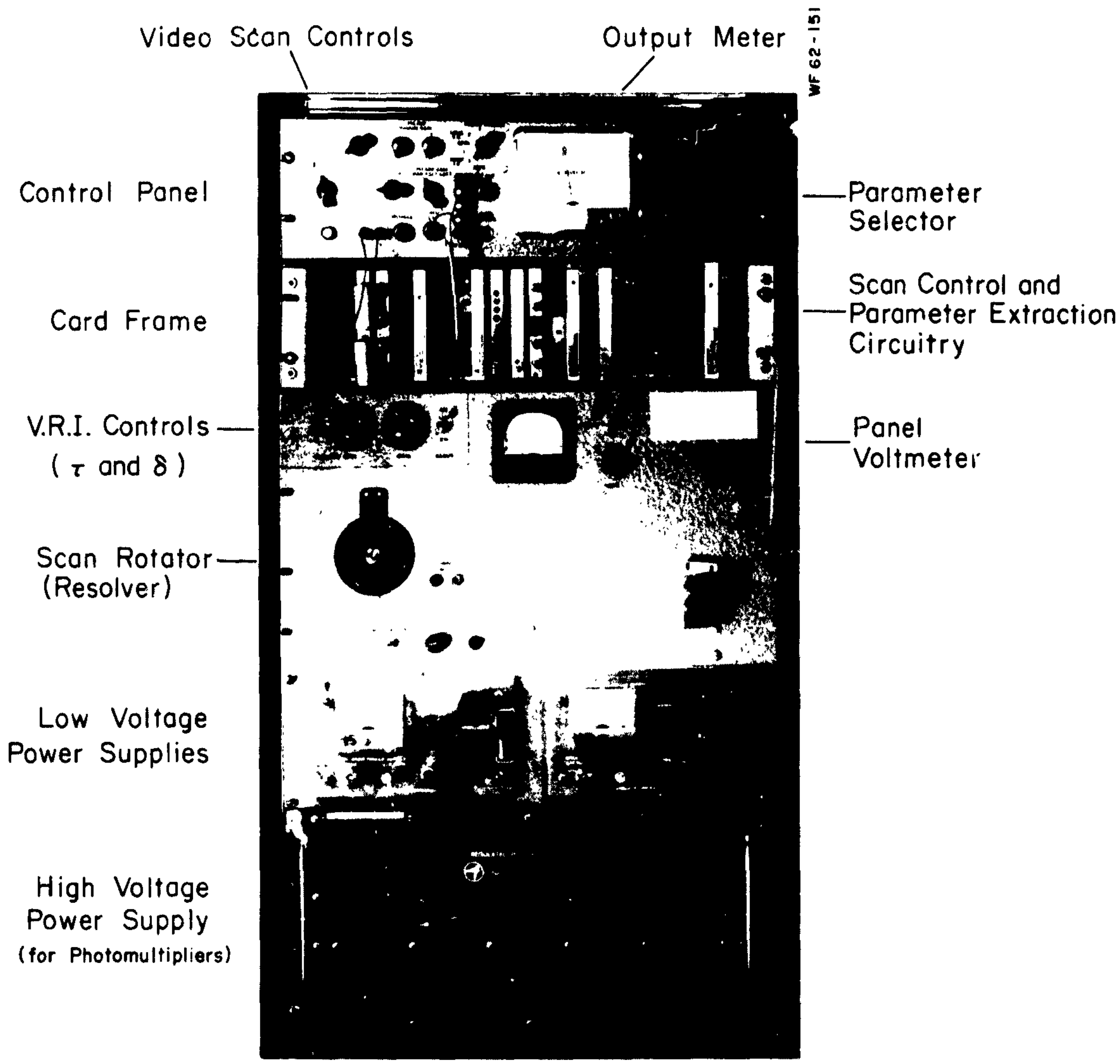


Figure I. 18 Electronics Rack

SIZE	DRAWING NUMBER	ISSUE
A	W2494 027	1

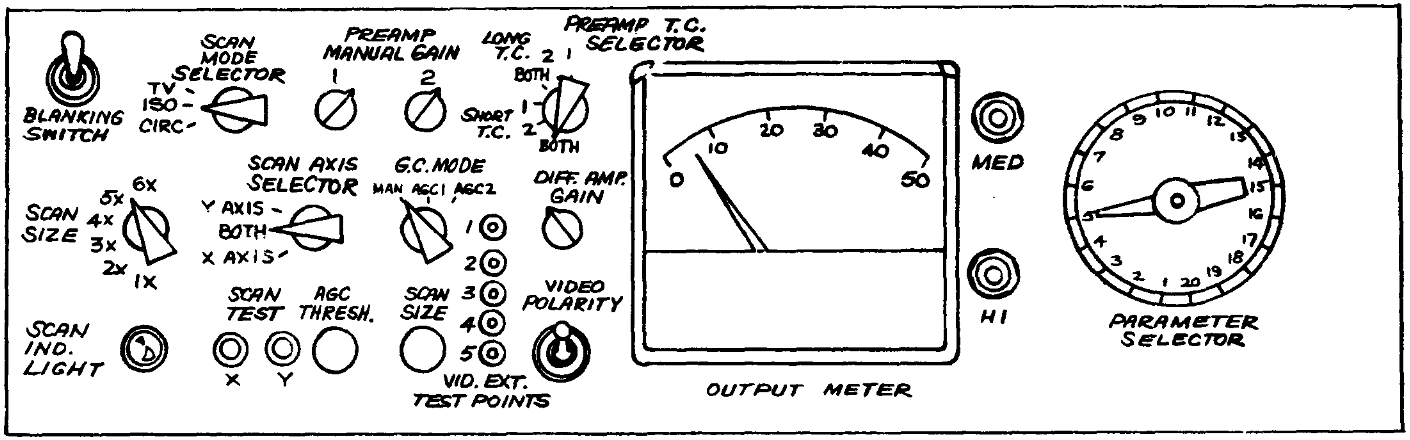


Figure I. 19

TITLE	SATRD CONTROL PANEL LAYOUT	
DRAWN	R E Dudley	DATE 6-29-62
CHECKED		DATE
APPROVED		DATE

REVISIONS		
NO.	INITIALS	DATE

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SIZE	DRAWING NUMBER	ISSUE
A	W 2494 027	1

6. X and Y Scan Test Points - These two jacks are directly connected to the X and Y input lines to the flying spot scanner. A monitor scope or other instruments may be plugged into these test points for alignment or to provide a monitor picture of the pattern present on the face of the CRT in the flying spot scanner.

7. Preamp and Time Constant Selector Switch - This six position switch selects three combinations of video inputs to the difference amplifier, for each of two time constants. The video channel combinations are: channel 1 only (No. 2 input grounded), channel 2 only (No. 1 input grounded), and both inputs simultaneously. The two time constants are 20 milliseconds and 5 seconds.

8. Gain Control Mode Selector Switch - This three position switch selects one of the following: manual control of preamp gains, AGC of channel 1, or AGC of channel 2. When the AGC mode is selected, the preamp gain pots used for the manual mode are opened and have no affect on the AGC loop gain.

9. AGC Threshold Potentiometer - This control adjusts the signal level at which AGC action is initiated.

10. Preamp Manual Gain Control Potentiometer - Two of these potentiometers are provided, one for each preamplifier. These controls vary preamplifier transfer impedance over the range of 3-75 K.

11. Difference Amplifier Gain Control Potentiometer - This potentiometer varies difference amplifier gain in the range of 0-50.

12. Video Polarity Switch - This is a reversing switch which interchanges inputs to the video difference amplifier and thereby changes the sign of the difference amplifier output.

13. Video and Extractor Test Points - There are five test points on the control panel which are connected as follows:

Test Point No. 1 - Output of one-shot multivibrator in the detail extractor circuit which signifies boundary crossings.

Test Point No. 2 - Blank

Test Point No. 3 - "+" input to video difference amplifier

Test Point No. 4 - "-" input to video difference amplifier

Test Point No. 5 - Output of difference amplifier

14. Parameter Selector Switch - This multi-position switch selects the outputs which will be displayed on the output meter and also brought out to two pairs of terminals for driving an external two-channel recorder. The following abbreviations are used on the controls of the equipment panel.

a) D/UA - Detail Per Unit Area
b) UNIF - Degree of Uniformity
c) DAM - Degree of Area Match
d) VRI - Voltage Range Indicator

The signals brought out to the output meter and to the recorder jack terminals for each position of the parameter selector switch are indicated below, and see Figure I.20:

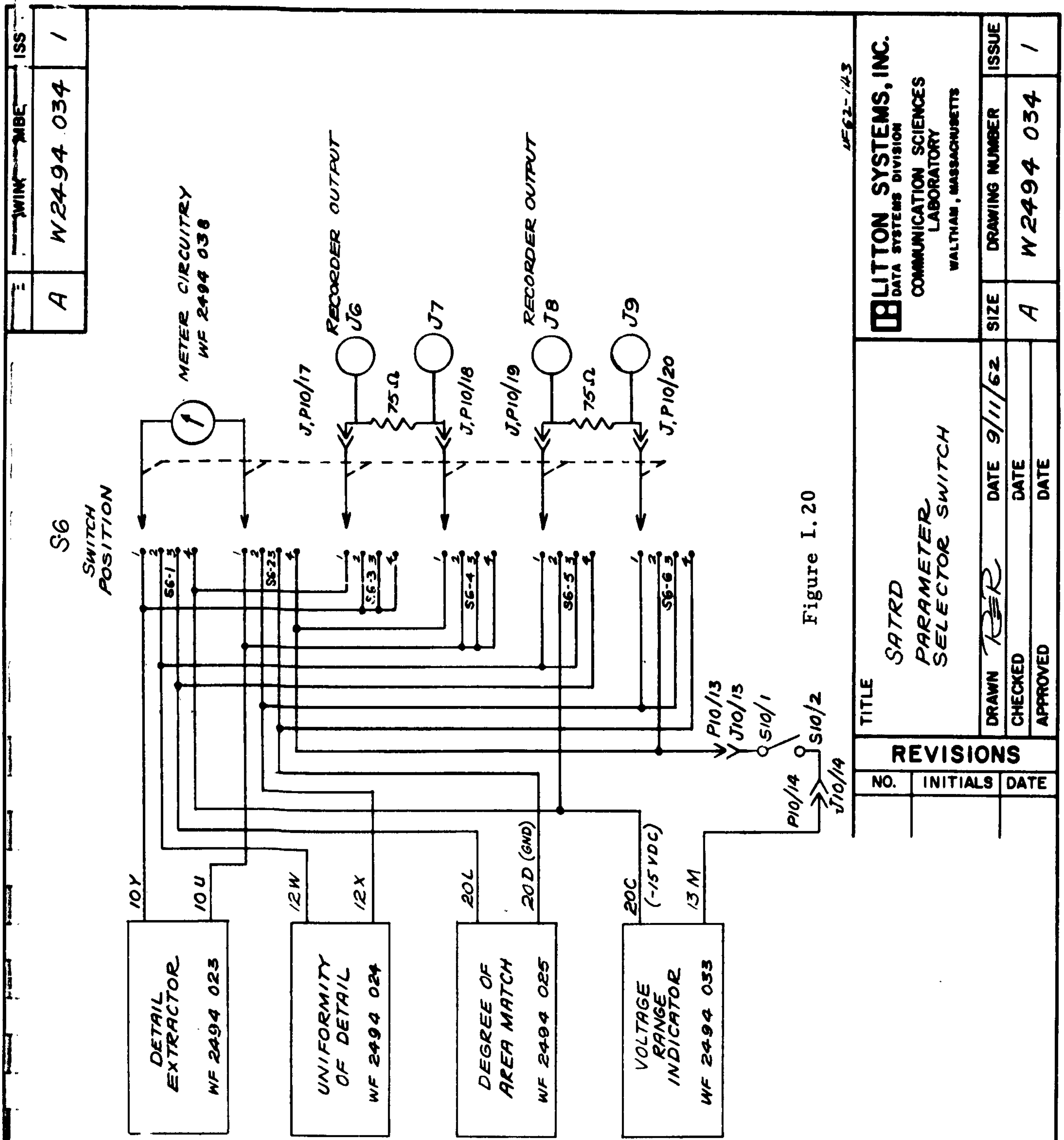
Parameter Switch Position	Output Meter Reads	Recorder Channel No.	
1	D/UA	VRI	UNIF
2	UNIF	D/UA	VRI
3	DAM	D/UA	UNIF
4	VRI	D/UA	DAM

15. Output Meter - The output meter has a sensitivity of 1000 microamperes full scale.

16. Meter Sensitivity Switches (push buttons) - Two such push button switches increase the output meter sensitivity by factors of 4 and 20, to 250 and 50 microamperes full scale sensitivity, respectively.

Card Frame

The card frame holds the following plug-in circuit cards. (Card numbers refer to corresponding numbered slots in the frame.)



S6
SWITCH POSITION
METER CIRCUITRY
WF 2494 038
RECORDER OUTPUT
J6
J7
RECORDER OUTPUT
J8
J9
75 Ω
75 Ω
J,P10/17
J,P10/18
J,P10/19
J,P10/20
S6-1
S6-2
S6-3
S6-4
S6-5
S6-6
P10/13
J10/13
S10/1
S10/2
P10/14
J10/14
10Y
10U
12W
12X
20L
20D (GND)
20C (-15 VDC)
13M
DETAIL EXTRACTOR
WF 2494 023
UNIFORMITY OF DETAIL
WF 2494 024
DEGREE OF AREA MATCH
WF 2494 025
VOLTAGE RANGE INDICATOR
WF 2494 033
LITTON SYSTEMS, INC.
DATA SYSTEMS DIVISION
COMMUNICATION SCIENCES LABORATORY
WALTHAM, MASSACHUSETTS
TITLE
SATRD
PARAMETER SELECTOR SWITCH
DRAWN
DATE 9/11/62
CHECKED
DATE
APPROVED
DATE
SIZE
A
DRAWING NUMBER
W2494 034
ISSUE
1
REVISIONS
NO.
INITIALS
DATE

Figure I.20

Card No. 1 - Stationary TV and rotating TV scan circuitry

Card No. 2 - Isotropic Scan and Blanking Circuit

Card No. 4 - Isotropic Sawtooth Frequency Generators

Card No. 7 - Difference Amplifier

Card No. 8 - Scan Scaling Potentiometers (and emitter followers) and Scan Indicator Circuit

Card No. 9 - Resolver Driver Circuitry

Card No. 10 - Detail Extractor Circuit

Card No. 12 - Uniformity of Detail Extractor Circuit

Card No. 13 - Voltage Range Indicator Circuit

Card No. 20 - Degree of Area Match Circuit

The motor drive switch for the resolver used for scan rotation is mounted on the front panel. A 0-360° dial indicates the angular position of the resolver, and a cam operated switch provides a contact closure once per revolution for monitoring purposes.

The Threshold and Range controls for the Voltage Range Indicator Circuit are mounted on the front panel.

A multi-range voltmeter has been installed for convenience in monitoring test points on cards when new parameter extraction circuits are being developed.

Two solid state power supplies are mounted in this section of the rack to provide +10 and -15 volts. Each supply panel contains a power switch, monitor meter, and coarse and fine voltage setting knobs.

<u>High Voltage Power Supply</u>

This unit provides high voltage for the photomultiplier tubes. Front panel controls are a power switch, operating mode switch (a standby or normal operation), and coarse and fine voltage setting knobs.